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Resource Conservation and Utilization in
Animal Waste Management. Volume II. Use of
Aerobic Stabilization to Enhance the
Value of Animal Manures on Feedstuffs

Cornell Univ.
Ithaca, NY

Prepared for

Robert S. Kerr Environmental Research Lab.
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ANIMAL WASTE MANAGEMENT - VOLUME II

Use of Aerobic Stabilization to Enhance the
Value of Animal Manures as Feedstuffs

by

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FOREWORD

EPA is charged by Congress to protect the Nation's land, air and water systems. Under a mandate of national environmental laws focused on air and water quality, solid waste management and the control of toxic substances, pesticides, noise, and radiation, the Agency strives to formulate and implement actions which lead to a compatible balance between human activities and the ability of natural systems to support and nurture life. In partial response to these mandates, the Robert S. Kerr Environmental Research Laboratory, Ada, Oklahoma, is charged with the mission to manage research programs to investigate the nature, transport, fate, and management of pollutants in ground water and to develop and demonstrate technologies for treating wastewaters with soils and other natural systems; for controlling pollution from irrigated crop and animal production agricultural activities; for controlling pollution from petroleum refining and petrochemical industries; and for managing pollution resulting from combinations of industrial/industrial and industrial/municipal wastewaters.

This phase of the project was initiated to evaluate the potential of aerobic stabilization to increase the value of animal manure as feedstuffs. Results indicate that the essential amino acid content of laying hen manure can be substantially increased by short-term aeration. These results along with the economic analysis appears to be adequate to justify the use of aeration of poultry wastes for waste stabilization, odor control and utilization as a feedstuffs. The information is useful in determining the optimal practices for waste management systems which will lead to the development of Best Management Practices for poultry wastes.

Clinton W. Hall

Clinton W. Hall, Director
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ABSTRACT

Previous research has demonstrated that aerobic stabilization can be an effective process for reducing the air (odor) and water pollution potential of livestock and poultry manures. This investigation evaluated the potential of aerobic stabilization to increase the value of animal manures as feedstuffs. Laboratory scale batch and continuous flow studies using laying hen manure as a substrate were conducted. The batch studies conducted were for periods of 15 and 10 days. Completely mixed continuous flow reactors were operated at retention times of 3, 5 7, and 10 days.

Results from both sets of studies indicated that the essential amino acid content and thus the potential value of laying hen manure as a feedstuff can be substantially increased with short-term aeration. In the continuous flow studies, a retention time of three days resulted in a 22% increase in the quantity of essential amino acids present. Longer periods of aeration (retention times exceeding three days) were found to be detrimental to the potential value of laying hen manure as a source of amino acids.

Aerobically stabilized laying hen manure appears to be a well balanced source of the essential amino acids required by White Leghorn laying hens. Such stabilized manure generally is comparable to soybean meal in essential amino acid composition. If used to replace tap water, aerobically stabilized laying hen manure could furnish up to 10% of the daily protein requirement (1.7 gm/hen-day) of a White Leghorn laying hen and result in an estimated reduction in feed costs of \$0.017/dozen eggs produced. This appears to be adequate to justify the cost of aeration for waste stabilization and odor control.

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LIST OF ABBREVIATIONS AND SYMBOLS

COD	-- Chemical Oxygen Demand
Kcal	-- Kilogram calorie
NH ₃ -N	-- Ammonia Nitrogen
NO ₂ -N	-- Nitrite Nitrogen
NO ₃ -N	-- Nitrate Nitrogen
ODML	-- Oxidation Ditch Mixed Liquor
ODR	-- Oxidation Ditch Residue
ON	-- Organic Nitrogen
S ₀	-- Initial Concentration
S _T	-- Concentration at a Specific Time
SRT	-- Solids Retention Time
TKN	-- Total Kjeldahl Nitrogen
TS	-- Total Solids
VS	-- Volatile Solids

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SECTION 1

INTRODUCTION

Results from several studies have indicated that aerobically stabilized animal manures can have significant nutritive value when used as dietary supplements for livestock and poultry. Results from these studies also have indicated that aerobic stabilization can increase the nutritive value of animal manures particularly as sources of amino acids. This investigation was concerned with the amino acid transformations that occur as animal manures are stabilized aerobically. The following paragraphs summarize the results of previous research on this topic.

BACKGROUND

Interest in the possible nutritive value of aerobically stabilized animal manures spans more than a decade. In one of the early studies (Harmon et al., 1969), the value of aerobically stabilized swine manure solids as a source of protein and energy was evaluated in a series of feeding trials using weanling rats. The stabilized swine manure solids, called oxidation ditch residue (ODR), were obtained by allowing oxidation ditch mixed liquor (ODML) solids to settle and then removing and discarding the supernatant.

The detailed results from this study, (Harmon et al., 1972), indicated that the ODR had nutritive value as a source of both protein and energy. Weight gains of the weanling rats were not decreased until ODR replaced more than one-third to one-half of the casein or soybean meal in the control diet. However, feed consumption per unit weight gain (gm feed/gm gain), commonly referred to as feed efficiency, increased. This increase indicates that the ODR was less digestible than the feedstuffs that were replaced. The ODR was deficient in both lysine and tyryptophan which are essential amino acids for rats. Additional details and results of this study are summarized in Table 1.

Harmon et al. (1971) fed fortified corn-soybean meal diets containing 0.0%, 4.0%, 8.0%, and 12.0% freeze dried swine ODML to weanling rats and reported comparable weight gains and feed efficiencies for the 0.0% and 4.0% diets. However, the diets containing 8.0% and 12.0% freeze dried swine ODML decreased both weight gain and efficiency. The freeze dried ODML, which was passed through a 20 mesh (841 micron opening) screen to remove hair, bran, and other coarse solids, contained 41.5% protein and 1.27% lysine on a dry matter basis.

TABLE 1. PERFORMANCE OF WEANLING RATS FED OXIDATION DITCH RESIDUE* (ODR) IN PLACE OF CASEIN, STARCH, OR SOYBEAN MEAL (Harmon *et al.*, 1972).

Trial I. Substitution of ODR for Casein.				
Casein, %	20.0	16.7	13.3	10.0
ODR, %	0	10.3	20.6	31.0
Avg. Daily Gain, Gm/day	6.5	6.5	6.1	5.3
Feed consumption, Gm/day	14.4	15.4	17.3	17.8
Feed/Gain, Gm/Gm	2.2	2.4	2.8	3.4

Trial II. Substitution of ODR or Starch in Place of Casein.						
Casein, %	16.7		13.3		10.0	
Starch, %	10.3	0	20.6	0	31.0	0
ODR, %	0	10.3	0	20.6	0	31.0
Avg. Daily Gain, Gm/day	5.3	6.1	5.5	5.6	4.8	5.4
Feed consumption, Gm/day	16.8	13.8	16.5	14.8	15.7	14.7
Feed/Gain, Gm/Gm	2.6	2.8	2.7	3.0	3.1	2.9

Trial III. Use of ODR in Corn Starch-Soybean Meal Diets.				
Corn Starch, %	22.8	11.9	1.0	0
Soybean Meal, %	27.2	13.6	0	0
Lysine HCL, %	0	0	0	1.0
ODR, %	0	24.5	49.0	49.0
Avg. Daily Gain, Gm/day	4.8	5.3	0.9	0.3
Feed/Gain, Gm/Gm	2.7	3.3	16.1	50.0

Trial IV. Addition of Tryptophan and/or Lysine to a Basal Corn-ODR Diet.		
Diet	Average Daily Gain, Gm/Day	Feed per Gain Gm/Gm
Basal	0.9	13.7
Basal + 0.1% Tryptophan	0.9	13.7
Basal + 1.0% Lysine HCL	1.0	12.2
Basal + 0.1% Tryptophan + 0.1% Lysine HCL	1.5	8.8

*Aerobically stabilized swine manure solids from an oxidation ditch.

In a study evaluating alternatives for concentrating aerobically digested swine manure solids for use as a feedstuff, Holmes *et al.* (1971) found that over 80% of the suspended solids in swine ODML would pass through a 200 mesh (74 micron opening) screen. It was suggested that this fraction, described as being chocolate brown in color and gelatinous in consistency, consisted primarily of microbial cells. With this material, as the particle size decreased, the crude protein content (total Kjeldahl nitrogen x 6.25) increased exponentially (Figure 1). This led to the conclusion that the smaller size particles should have the greatest nutritive as sources of protein. This conclusion was supported by a comparison of the concentrations of several amino acids as a function of particle size (Table 2).

TABLE 2. AMINO ACID CONCENTRATION AS A FUNCTION OF PARTICLE SIZE*
FOR SWINE OXIDATION DITCH MIXED LIQUOR (Harmon, 1972).

Screen Mesh	Size Opening, Micron	Percent of Dry Matter				
		Lysine	Histidine	Threonine	Methionine	Isoleucine
20	841	0.38	0.24	0.98	0.32	0.81
50	297	0.92	0.52	1.57	0.42	1.13
100	149	1.36	0.98	2.01	0.62	1.66
200	74	3.08	1.32	2.44	1.27	2.20

*Particles passing through the noted size screen.

Harmon *et al.* (1973) found that swine ODML also had nutritive value when used as a supplemental source of protein for feeder pigs. The performance of feeder pigs fed 12% protein corn-soybean meal diets mixed with tap water and swine ODML were compared. The composition of the swine ODML used is described in Table 3. The use of swine ODML significantly ($P < 0.05$) increased both average daily gain and feed efficiency (Table 4). The researchers concluded that the observed improvement in animal performance resulted from the correction of a marginal amino acid deficiency. The addition of the swine ODML resulted in a 0.1% increase in the lysine content of the diet. Protein content was increased by 2.5%.

No significant differences were observed, however, when the performance of feeder pigs fed corn plus ODML versus corn plus tap water diets were compared (Table 4). The results of these two feeding trials indicate that aerobically stabilized manures can have value as a supplemental but not a primary source of protein.

Noting that a pig normally consumes twice as much water as dry feed, Harmon and Day (1974) compared the performance of feeder pigs receiving tap water and swine ODML as a tap water substitute. They found that using ODML

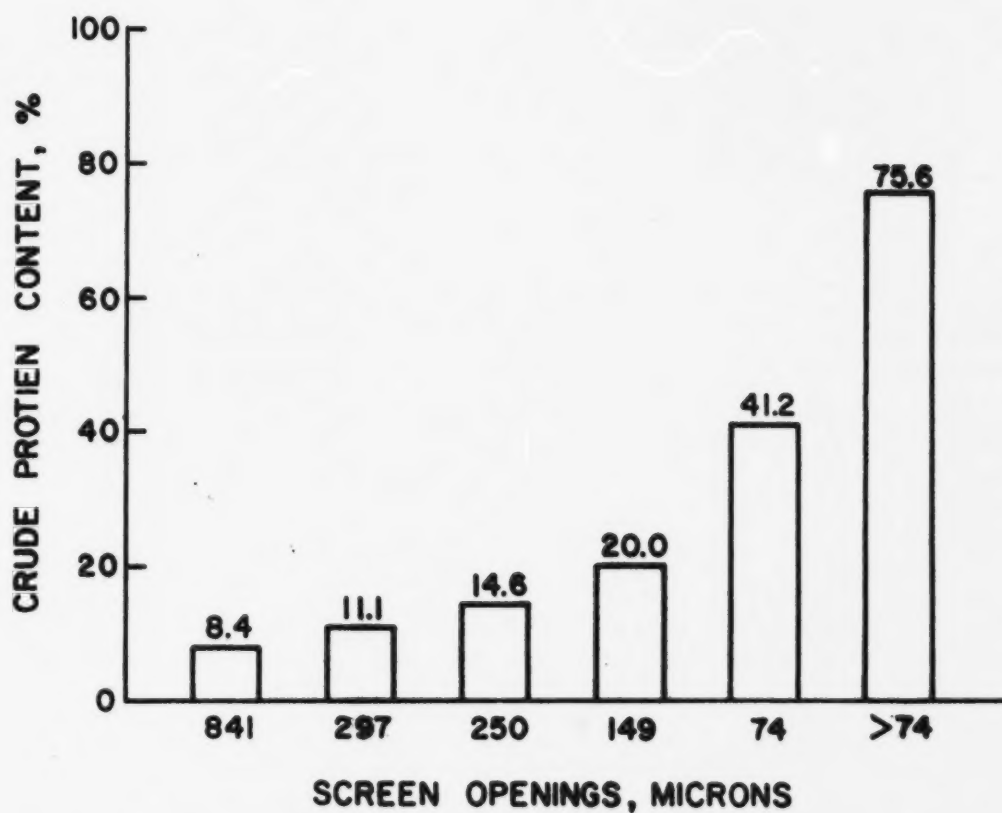


Figure 1. Crude protein content as a function of particle size for swine oxidation ditch mixed liquor.

TABLE 3. COMPOSITION OF SWINE OXIDATION DITCH MIXED LIQUOR USED BY HARMON ET AL. (1973) IN FEEDING TRIALS INVOLVING FEEDER PIGS.

Component	%, Dry Matter Basis*
Protein	49.0
Lysine	1.42
Histidine	0.47
Arginine	1.28
Threonine	1.96
Valine	2.06
Isoleucine	1.49
Leucine	2.79
Methionine	0.77
Aspartic Acid	3.73
Serine	2.55
Glutamic Acid	5.06
Proline	1.29
Glycine	2.29
Alanine	2.83
Tyrosine	1.17
Tryptophan	0.28
Calcium	3.33
Phosphorus	3.83
Magnesium	1.49
Sodium	2.75
Potassium	4.14

*Dry matter averaged 3.40%.

TABLE 4. PERFORMANCE OF FEEDER PIGS FED 12% PROTEIN CORN-SOYBEAN MEAL AND CORN DIETS COMBINED WITH SWINE OXIDATION DITCH MIXED LIQUOR AND TAP WATER (Harmon et al., 1973).

	Corn-Soybean Meal		Corn	
	Water	ODML	Water	ODML
Average Daily Gain, kg	0.52	0.56*	0.32	0.34
Feed Consumed per Unit Gain, kg/kg	4.02	3.76*	5.59	5.38

*Differences are significant ($P < 0.05$).

in place of tap water in combination with a 12% protein corn-soybean meal diet also improved average daily gain and feed efficiency (Table 5). These results are particularly interesting because of the simplicity of the utilization approach. Using aerobically stabilized manure as a tap water substitute eliminates the need to mix feed daily as well as possible feed spoilage problems.

Harmon and Day (1974) presented a comparison of concentrations of several essential amino acids present in swine oxidation ditch mixed liquor and in fresh and dried swine feces (Table 6). This comparison, in combination with the observation that the concentrations of several amino acids increased substantially as particle size decreased (Table 2), formed the basis for suggesting that the nutritive value of swine manure is upgraded microbially during aerobic digestion.

In a recent study, Frank *et al.* (1980) utilized swine ODML as a tap water substitute for feeder pigs in combination with diets deficient in vitamins, calcium and phosphorus, or protein. The use of ODML in place of tap water did not improve weight gain or feed efficiency when used in combination with either 12% or 14% protein corn-soybean meal diets. The ODML did not correct vitamin or calcium and phosphorus deficiencies. The results of this study were confounded, however, by high ODML nitrate nitrogen concentrations which ranged from 44 mg/l to 1600 mg/l. In previous studies, nitrate nitrogen concentrations normally ranged between 70 mg/l and 225 mg/l and never exceeding 370 mg/l (Harmon and Day, 1975). The high nitrate nitrogen concentrations in the diet could have affected the performance of the animals.

Feeding trials also have been conducted to assess the nutritive value of aerobically stabilized beef cattle and laying hen manures. Vetter (1972) combined beef ODML with a typical finishing ration and fed the mixture to feeder cattle. The results of the three feeding trials (Table 7) showed that the use of beef ODML had no consistent impact on either weight gain or feed efficiency. The statistical significance of the observed differences was not reported.

Hegg *et al.* (1974) fed settled solids obtained from a beef cattle oxidation ditch to feeder steers as a partial replacement for ground corn. It was concluded, based on observed animal performance, that this material had between 63% and 85% of the nutritive value of ground corn. This estimate was reduced to 50% based on the results of a subsequent feeding trial (Hegg *et al.*, 1975).

Martin (1980) reported a statistically significant ($P < 0.01$) increase in egg production when aerobically stabilized poultry manure was used as a tap water substitute for White Leghorn laying hens (Table 8). No significant differences in either egg quality or bird health were observed. In this study both control and experimental groups of birds received a typical 17% protein laying ration.

TABLE 5. PERFORMANCE OF FEEDER PIGS FED SWINE OXIDATION DITCH MIXED LIQUOR AS A TAP WATER SUBSTITUTE IN COMBINATION WITH A 12% PROTEIN CORN-SOYBEAN MEAL DIET. (Harmon and Day, 1974).

Replicate*	Avg. Daily Gain, kg		Feed/Gain, kg/kg	
	Tap Water	ODML	Tap Water	ODML
1	0.61	0.63	3.30	3.25
2	0.66	0.70	3.38	3.37
3	0.77	0.90	4.10	2.92
4	0.60	0.72	4.35	3.60
5	0.58	0.66	3.85	3.80
6	0.71	0.79	3.23	2.96
$\bar{X}$	0.66	0.73	3.70	3.32

*Each replicate represents results from 10 pigs.

TABLE 6. COMPARISON OF THE AMINO ACID COMPOSITION OF SWINE OXIDATION DITCH MIXED LIQUOR AND FRESH AND DRIED SWINE FECES (Harmon & Day, 1974).

Amino Acid	-----Percentage of Dry Matter-----			
	Fresh Swine Feces*	Dried Swine Feces†	Oxidation Ditch Mixed Liquor§	Oxidation Ditch Mixed Liquor†
Phenylalanine	0.81	0.87	1.48	1.66
Lysine	0.60	1.11	1.42	1.60
Arginine	0.44	0.67	1.28	1.45
Threonine	0.53	0.80	1.96	1.22
Methionine	--	0.58	0.77	0.60
Isoleucine	0.52	1.03	1.49	1.54
Leucine	0.92	1.57	2.79	2.13

*Gouwens (1966)

†Orr et al. (1973)

§Harmon et al. (1972)

TABLE 7. PERFORMANCE OF FEEDER CATTLE FED BEEF OXIDATION DITCH MIXED LIQUOR COMBINED WITH A TYPICAL FINISHING RATION (Vetter, 1972).

Trial Treatment	I (133 Days)		II (111 Days)		III (119 Days)	
	Control	ODML	Control	ODML	Control	ODML
Avg. Daily Gain, kg	1.58	1.59	1.30	1.36	1.38	1.30
Ration Fed, kg Dry Matter	10.10	10.95	9.33	9.52	9.78	8.84
ODML Fed, kg Dry Matter	--	0.23*	--	0.41	--	0.32
Ration Fed per Unit Gain, kg/kg	6.39	6.66	7.18	7.00	7.09	6.80

*Average, 0.37 for final 49 days.

TABLE 8. COMPARISON OF EGG PRODUCTION LEVELS OF WHITE LEGHORN HENS RECEIVING TAP WATER AND AEROBICALLY STABILIZED LAYING HEN MANURE (Martin, 1980).

Trial	Duration, Months	Egg Production, Hen-Day Percent		
		Tap Water	Aerobically Stabilized Laying Hen Manure	Differential, Percent*
I	6	66.6	68.6	+2.0
II	8	76.7	79.8	+3.1
III	8	77.2	80.0	+1.3

*Differences in average egg production within each trial are significant ($P < 0.01$).

The use of aerobically stabilized poultry manure as a tap water substitute for laying hens also has been evaluated by Johnson et al. (1977). However, mixed liquor nitrate nitrogen concentrations were not controlled in the study and reached 1300 mg/l. As a result, egg production, on a hen-day basis, decreased from 64.7% for the first week of the study to 1% during week seven.

PROJECT OBJECTIVES

The results of the studies summarized in the preceding discussion have demonstrated that aerobically stabilized livestock and poultry manures have nutritive value and can be utilized successfully as supplemental sources of protein and energy. However, the underlying hypothesis, that aerobic stabilization enhances the nutritive value of manures particularly as sources of amino acids, has received little attention. Although Harmon and Day (1974) have shown that concentrations of several essential amino acids are much greater in aerobically stabilized swine manure as compared to freshly excreted swine manure (Table 6), the nature of the transformations responsible for these increases is unknown. Since these comparisons were made on a dry matter basis, it is possible that the increases only result from solids destruction rather than microbial amino acid synthesis. In addition, the potential for utilizing aerobic stabilization to maximize the nutritive value of manures is unknown. Aerobically stabilized manures have been used as feedstuffs on an "as available" basis.

This investigation evaluated the potential of aerobic stabilization to increase the value of laying hen manure as a feedstuff. Specific objectives included:

1. Determination of the nature of the amino acid transformations that occur as laying hen manure is stabilized aerobically.
2. Evaluation of solids retention time (SRT) as an aeration system design and operating parameter for maximizing amino acid content and quality.
3. Characterization of the relationship between amino acid transformations and waste stabilization.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

From the results of these studies, it can be concluded that:

1. Aerobic stabilization has merit as a process for: (a) reducing the air (odor) and water pollution potential of laying hen manure and (b) enhancing the essential amino acid content and thus the potential value of laying hen manure as a feedstuff.
2. Short-term aeration (3-4 days) significantly increases the essential amino acid content and thus the potential value of laying hen manure as a feedstuff.
3. Long-term aeration (>3-4 days): (a) reduces the value of aerobically stabilized laying hen manure as a source of amino acids and (b) provides little additional benefit to stabilization.
4. Solids retention time (SRT) can be used as a basis for system design and process control for both amino acid enhancement and waste stabilization.
5. The potential value of aerobically stabilized laying hen manure as a feedstuff appears adequate to justify the use of aeration for waste stabilization and odor control.
6. The use of aerobic stabilization to enhance the nutritive value of livestock and poultry manures as feedstuffs has merit and deserves further study.

RECOMMENDATIONS

It is recommended that:

1. Laboratory scale continuous flow studies be conducted using laying hen manure as a substrate to characterize the nature of amino acid transformations that occur at solid retention times of less than three days.

2. Digestibility studies using established methodology be conducted to determine amino acid availability and the value of aerobically stabilized laying hen manure with high amino acid concentrations as a source of energy.
3. The question of ammonia toxicity when aerobically stabilized laying hen manure is used as a feedstuff should be examined since the short retention times necessary to maximize essential amino acid content precludes nitrification.
4. Long term feeding trials should be conducted comparing animal performance with nutritionally complete and marginally deficient diets supplemented with aerobically stabilized laying hen manure containing high amino acid concentrations. Results of digestibility studies should be used in combination with established feed formulation practices to formulate experimental diets. Both egg production and feed conversion efficiency should be used as criteria for assessing animal performance.

SECTION 3

METHODS AND MATERIALS

In order to characterize and quantify the amino acid transformations that occur as animal manures are stabilized aerobically, laboratory scale batch and continuous flow studies were conducted using laying hen manure as the substrate. Four liter glass serum bottles were used as reactors for both batch and continuous flow studies. Compressed air was supplied continuously via fritted gas dispersion tubes at rates necessary to maintain measurable dissolved oxygen concentrations (>0.5 mg O_2/l) in the reactors at all times. The mixing action of the compressed air was supplemented using magnetic stirrers and teflon coated stirring bars to maintain completely mixed conditions. Equipment details are sketched in Figure 2. All studies were conducted at ambient laboratory temperatures of $20 \pm 2^\circ C$.

The manure utilized in these studies was collected from caged White Leghorn laying hens housed at the Agricultural Waste Management Laboratory, Cornell University. The birds were of the Shaver strain and received a typical laying ration (Table 9) containing 2930 Kcal metabolizable energy/kg of feed.

The manure used for these studies was collected over 24 hour time periods by suspending a tray below an individual cage containing three birds. Collection periods were limited to 24 hours to minimize chemical and microbial transformations prior to utilization. Following removal of extraneous materials, primarily wasted feed and feathers, the collected manure was either refrigerated at $4^\circ C$ or frozen for long term storage and subsequent use.

Mixed liquor from a pilot plant scale oxidation ditch stabilizing poultry manure was used as the source of an active, adapted microbial population for both batch and continuous flow studies. The chemical and physical characteristics of the mixed liquor used for each study are summarized in Table 10. The absence of both ammonia and nitrate nitrogen is the result of intermittent aeration in the oxidation ditch to achieve simultaneous nitrification and denitrification.

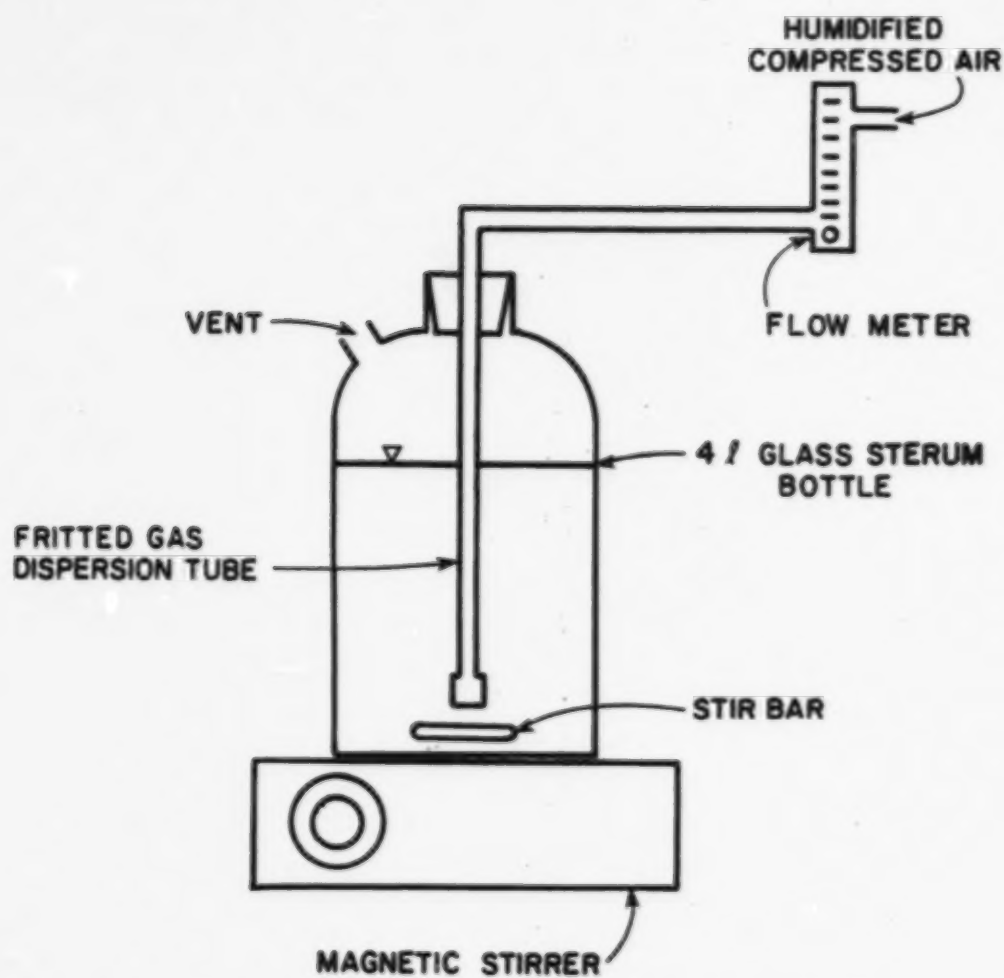


Figure 2. Schematic of reactors and ancillary equipment used for batch and continuous flow studies.

TABLE 9. COMPOSITION AND CALCULATED ANALYSIS OF RATION FED TO BIRDS PRODUCING THE MANURE UTILIZED FOR THESE STUDIES.

Composition	Amount (kg/tonne)
No. 2 Yellow Corn Meal	685
Stabilized Grease	10
Soybean Meal, Dehulled, 49% Protein	140
Corn Distillers Solubles with Grains	15
Meat and Bone Meal	60
Alfalfa Meal	10
Limestone	35
Oyster Shell	40
Salt, Iodized	2
Sodium Sulfate	0.5
Vitamin and Mineral Premix	2.5
Calculated Analysis:	(%)
Protein	16.1
Fat	4.4
Fiber	2.2
Calcium	3.47
Available Phosphorus	0.42
Linoleic Acid	1.48
Lysine	0.76
Methionine	0.36
Metabolizable Energy, Kcal/kg	2930

BATCH STUDIES

Separate batch studies were conducted for periods of 15 and 10 days, respectively. For each of these studies, an appropriate quantity of fresh laying hen manure was diluted with distilled water to produce 5.4 l of slurry that contained approximately 30 gm total solids/l to which 0.6 l of oxidation ditch mixed liquor was added. Following mixing, the resultant mixture was divided into two equal parts and placed in separate reactors that were operated simultaneously.

Reactor contents were analyzed on days 0, 1, 2, 3, 4, 7 and 15 for Batch Study I and on days 0, 1, 2, 2.5, 3, 3.5, 4, 7 and 10 for Batch Study II for the parameters indicated in Table 11. Corrections for evaporative losses using distilled water were made daily. Dissolved oxygen measurements also were made daily to insure that a residual concentration was present.

TABLE 10. CHARACTERISTICS OF OXIDATION DITCH MIXED LIQUOR UTILIZED TO INITIATE BATCH AND CONTINUOUS FLOW AMINO ACID SYNTHESIS STUDIES, mg/l.

	Total Solids	Volatile Solids	Total Kjeldahl Nitrogen	Ammonia Nitrogen	Nitrite Nitrogen	Nitrate Nitrogen	pH
<u>Batch Studies</u>							
I	25,180	15,640	1510	Trace	Trace	Trace	8.1
II	15,160	9,390	710	0	0	175	7.5
<u>Continuous Flow Studies</u>							
3 and 10 Day HRT	28,800	17,910	1570	0	0	0	8.0
5 Day HRT	23,990	14,920	1270	0	0	0	7.9
7 Day HRT	20,360	12,340	1030	0	0	0	8.0

TABLE 11. SUMMARY OF PARAMETERS MEASURED FOR BATCH AND CONTINUOUS FLOW AMINO ACID SYNTHESIS STUDIES.

	Batch Study I	Batch Study II	Continuous Flow Studies	
			Fresh Manure	Effluent
Total Solids (TS)	X	X	X	X
Volatile Solids (VS)	X	X	X	X
Total Kjeldahl Nitrogen (TKN)	X	X	X	X
Ammonia Nitrogen (NH ₃ -N)	X	X		X
Nitrite Nitrogen (NO ₂ -N)	X	X		X
Nitrate Nitrogen (NO ₃ -N)	X	X		X
Chemical Oxygen Demand (COD)	X	X	X	X
pH	X	X	X	X
Temperature	X	X		X
Oxygen Uptake Rate	X	X		X
Gross Energy	X	X		
Amino Acids	X	X	X	X

CONTINUOUS FLOW STUDIES

Continuous flow reactors were operated at retention times of 3, 5, 7 and 10 days without solids recycle. Thus, hydraulic and solid retention times were equal. The reactors initially were filled with oxidation ditch mixed liquor (Table 10). Each day, a volume of mixed liquor appropriate to achieve the respective retention time was removed and replaced with a comparable volume of fresh laying hen manure diluted with distilled water to form a slurry containing 30 gm total solids/l. Each reactor was operated for a period equivalent to three retention times to establish steady state conditions before reactor contents were analyzed for the physical and chemical characteristics indicated in Table 11. The fresh manure utilized as substrate also was analyzed for the same characteristics (Table 11) to permit determination of material balances and to characterize transformations of various constituents, particularly amino acids. The dissolved oxygen concentration was measured daily to insure that aerobic conditions were maintained.

ANALYTICAL METHODS

For this study, the following analytical techniques were utilized: total and volatile solids and chemical oxygen demand (Standard Methods, 1975); total Kjeldahl nitrogen - microKjeldahl method (McKenzie and Wallace, 1954); nitrate nitrogen - diazotization method (Montgomery and Dymock, 1961); and ammonia and nitrate nitrogen - steam distillation and salicylic methods, respectively (Prakassam et al., 1975).

Dissolved oxygen concentrations and temperature were measured with a Yellow Springs Instrument Company Model 54 oxygen meter. Oxygen uptake rates were determined using the method described by Loehr, 1977. A combination Ag/Ag Cl glass electrode with an Orion Ionanalyzer was used for pH measurements.

Samples for amino acid and gross energy determinations were frozen and freeze dried. The freeze dried samples were ground using a Wiley mill with a 40 mm mesh screen. Gross energy determinations were made using an adiabatic bomb calorimeter. Amino acid analyses were performed by personnel of the Amino Acid Analysis and Protein Sequencing Facility, College of Veterinary Medicine, Cornell University. Samples were hydrolyzed using 6 N hydrochloric acid for 24 hours at 110°C prior to analysis by a Beckman 119CL Amino Acid Analyzer equipped for single column analysis of hydrolysates. Each sample was analyzed for the following amino acids: alanine, arginine, aspartic acid, glutamic acid, glycine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, proline, serine, threonine, tyrosine, and valine.

SECTION 4

RESULTS

The following summarizes the results of the batch and continuous flow studies described in Section 3.

RAW WASTE CHARACTERISTICS

The characteristics of the laying hen manure used as substrate for both batch and continuous flow studies are summarized in Table 12. Although there was some variation between individual manure samples, these differences were assumed to be primarily the result of sampling and analytical variations. Thus, the means presented in Table 12 were used as the basis for all material balances presented and discussed in subsequent paragraphs.

BATCH STUDIES

As noted in Section 3, two independent batch studies were conducted. The first, Batch Study I, was conducted for 15 days and Batch Study II for 10 days. Since the results from the two studies are similar, they are presented together. As initial concentrations of amino acids and other parameters of interest differed slightly, the format of expressing a concentration at a specific time, S_T , as a fraction of the initial concentration, S_0 , i.e. S_T/S_0 , to compare results from the two studies will be used as appropriate.

Results of the amino acid analyses performed during each study are summarized in Tables 13 and 14. These data show that the composition of laying hen manure amino acids changed substantially during the initial period, 3 to 4 days, of aeration. One result of these changes was a significant increase in essential amino acids expressed as a percentage of total amino acids. Another result was an apparent increase in amino acid quantity. The term apparent is used because expressing amino acid content as a percentage of initial total solids reflects not only possible microbial increases in the mass of amino acids present but also the biological destruction of total solids.

As shown in Figure 3, substantial reductions (up to 50%) in mixed liquor concentrations of total and volatile solids occurred in each batch study. Results of calculations to convert the amino acid concentrations presented as percentages of total solids (Tables 13 and 14) to a mass-volume, mg/l, basis (Table 15) show that the previously noted increases

TABLE 12. CHARACTERISTICS OF LAYING HEN MANURE USED
IN BATCH AND CONTINUOUS FLOW STUDIES.

Parameter	Mean	Std. Dev.	n*
Total Solids (TS), %	20.7	1.3	15
Volatile Solids (VS), % of Total Solids	74.3	3.5	15
Total Kjeldahl Nitrogen (TKN), mg TKN/gm TS	89.3	8.1	15
Chemical Oxygen Demand (COD), mg COD/gm TS	823.	88.	12
Amino Acids, (AA), mg AA/gm TS			
Aspartic Acid	14.1	1.2	4
Threonine†	6.0	0.9	4
Serine	6.0	0.6	4
Glutamic Acid	17.2	1.4	4
Proline	7.0	0.5	4
Glycine	38.1	5.4	4
Alanine	10.6	0.7	4
Valine†	7.0	0.7	4
Methionine†	2.4	0.2	4
Isoleucine†	9.0	1.7	4
Leucine†	9.4	0.7	4
Tyrosine	3.6	0.4	4
Phenylalanine†	4.9	0.3	4
Histidine†	2.8	0.2	4
Lysine†	7.0	0.5	4
Arginine†	6.0	0.7	4
Total Amino Acids	151.0	11.8	4
Essential Amino Acids	54.4	2.5	4

* n = number of observations.

† amino acids essential for the chicken.

TABLE 13. AMINO ACID COMPOSITION OF LAYING HEN MANURE DURING BATCH AEROBIC STABILIZATION -
BATCH STUDY I.

Amino Acid, % TS.*	Time of Aeration, Days						
	0	1	2	3	4	7	15
Alanine	0.79	1.07	1.14	1.31	1.26	1.19	0.97
Arginine†	0.56	0.78	0.80	0.92	0.88	0.85	0.64
Aspartic Acid	1.23	1.61	1.66	1.82	1.74	1.59	1.22
Glutamic Acid	1.51	1.96	1.97	2.19	2.09	1.91	1.45
Glycine	1.90	1.93	0.99	1.05	1.03	1.02	0.84
Histidine†	0.15	0.31	0.30	0.32	0.30	0.27	0.19
Isoleucine†	0.59	0.76	0.79	0.96	0.92	0.80	0.65
Leucine†	0.85	1.17	1.22	1.37	1.28	1.17	0.94
Lysine†	0.65	0.93	0.92	1.03	0.96	0.79	0.48
Methionine†	0.26	0.36	0.38	0.49	0.47	0.42	0.15
Phenylalanine†	0.48	0.65	0.69	0.75	0.71	0.66	0.51
Proline	0.59	0.67	0.69	0.76	0.75	0.77	0.62
Serine	0.51	0.65	0.67	0.77	0.76	0.71	0.52
Threonine†	0.52	0.69	0.74	0.80	0.77	0.73	0.59
Tyrosine	0.35	0.49	0.50	0.57	0.53	0.47	0.21
Valine†	0.66	0.96	1.00	1.11	1.03	0.95	0.74
Total Amino Acids	11.60	14.99	14.46	16.22	15.48	14.30	10.72
Essential Amino Acids, % of Total	40.7	44.1	47.3	47.8	47.3	46.4	45.6

* % of total solids (dry matter).

† essential amino acids.

TABLE 14. AMINO ACID COMPOSITION OF LAYING HEN MANURE DURING BATCH AEROBIC STABILIZATION -
BATCH STUDY II.

Amino Acid, % TS*	Time of Aeration, Days									
	0	1	2	2.5	3	3.5	4	7	10	
Alanine	0.93	0.88	1.14	1.38	1.27	1.36	1.38	1.28	1.27	
Arginine†	0.53	0.62	0.85	0.99	0.93	0.99	1.02	0.92	0.92	
Aspartic Acid	1.22	1.38	1.80	1.95	1.86	1.97	2.01	1.79	1.73	
Glutamic Acid	1.43	0.92	2.04	2.28	2.14	2.29	2.34	2.14	2.04	
Glycine	3.03	1.80	1.08	1.15	1.09	1.14	1.15	1.07	1.08	
Histidine†	0.27	0.29	0.36	0.37	0.35	0.37	0.37	0.32	0.31	
Isoleucine†	0.67	0.73	0.98	1.12	1.09	1.15	1.18	0.99	1.06	
Leucine†	0.90	1.05	1.37	1.56	1.48	1.56	1.56	1.35	1.41	
Lysine†	0.61	0.73	0.97	1.08	1.00	1.08	1.12	0.86	0.79	
Methionine†	0.25	0.27	0.43	0.33	0.29	0.30	0.31	0.32	0.25	
Phenylalanine†	0.50	0.59	0.76	0.87	0.83	0.88	0.88	0.77	0.73	
Proline	0.60	0.57	0.73	0.81	0.78	0.81	0.81	0.77	0.79	
Serine	0.49	0.51	0.67	0.76	0.74	0.77	0.80	0.75	0.75	
Threonine†	0.53	0.59	0.77	0.88	0.83	0.89	0.92	0.83	0.82	
Tyrosine	0.35	0.43	0.59	0.63	0.61	0.63	0.65	0.51	0.44	
Valine†	0.65	0.78	1.02	1.19	1.13	1.19	1.19	1.06	1.03	
Total Amino Acids	12.96	12.67	15.56	17.32	16.42	17.38	17.67	15.73	15.42	
Essential Amino Acids, % of Total	37.9	44.5	48.3	48.4	48.3	48.4	48.3	47.2	47.5	

* % of total solids (dry matter).

† essential amino acids.

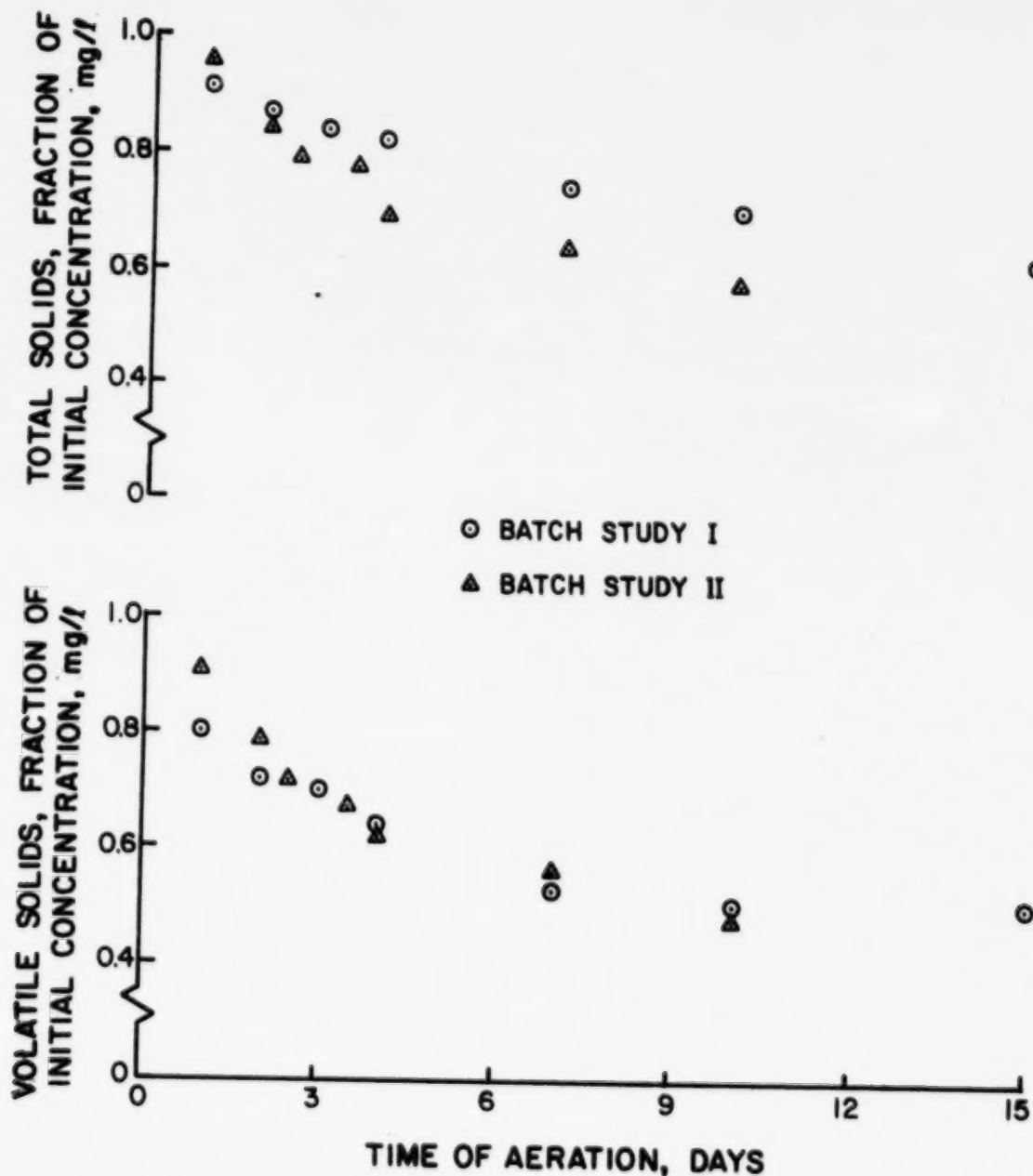


Figure 3. Mixed liquor total and volatile solids concentrations, expressed as fractions of initial concentrations, as a function of aeration time during batch aerobic stabilization.

TABLE 15. CHANGES IN CONCENTRATIONS (MG/L) OF TOTAL AND ESSENTIAL AMINO ACIDS WITH TIME OF AERATION -
BATCH STUDIES I AND II.

Time of Aeration, Days	Total Amino Acids, mg/l	Essential Amino Acids*, mg/l	Total Amino Acids, mg/l	Essential Amino Acids*, mg/l
0	4170	1697	3926	1488
1	4910	2165	3613	1608
2	4518	2137	3941	1904
2.5	--	--	4161	2014
3	4919	2351	3843	1856
3.5	--	--	3866	1871
4	4606	2179	3713	1793
7	3522	1634	3004	1418
10	--	--	2715	1290
15	2434	1110	--	--

*Amino acids essential for the chicken.

largely are apparent reflecting total solids destruction. Although actual increases in amino acid concentrations on a mg/l basis were, at best, nominal (Table 15 and Figure 4), there were substantial increases in essential amino acid concentrations in both studies (Table 15 and Figure 5). These increases occurred during the initial phase, 2.5 to 3 days, of aeration in both studies.

The declines in both total and essential amino acid concentrations after about four days (Figures 4 and 5) appear to be the result of endogenous respiration. It should be noted that the percent of essential amino acids did not decline appreciably during this period (Tables 13 and 14).

In both studies, mixed liquor gross energy concentrations, Kcal/l, declined with time (Figure 6) reflecting decreases in mixed liquor volatile solids concentrations (Figure 3). However, slight increases in the gross energy content of the remaining volatile solids were observed in both studies with maximum levels achieved during the first 2 to 3 days of aeration (Figure 7).

As illustrated in Figure 3, significant reductions in mixed liquor volatile solids concentrations occurred in both batch studies. These reductions are indicative of the microbial oxidation of biodegradable carbonaceous compounds producing carbon dioxide and water as end-products. Thus, volatile solids destruction is a useful parameter to characterize stabilization. However, not all carbonaceous compounds contained in laying hen manure are readily biodegradable (Martin and Loehr, 1977). To provide a more accurate basis for examining the relationship between manure stabilization and amino acid transformations during aerobic digestion, the methodology developed by Foree and McCarty (1968) was used to determine the biodegradable and refractory fractions of the manure used in these studies. Using volatile solids data from both batch studies, it was determined that only about 50% of the volatile solids in the initial laying hen manure used in the studies were readily biodegradable (Figure 8).

As shown in Figure 9, destruction of biodegradable volatile solids was essentially complete in both studies after 10 days of aeration with over 50% of the destruction occurring within the first three days. Decreases in oxygen uptake rates (Figure 10) and chemical oxygen demand (Figure 11) also indicate that stabilization was essentially complete in 10 days.

In these studies, nitrogen transformations were of interest due to the possibility of competition between the heterotrophic microbial population and the nitrifying bacteria, Nitrosomas and Nitrobacter, for ammonia nitrogen. However, the presence of residual ammonia nitrogen concentrations through day 10 in both studies indicated that amino acid synthesis was not limited by available nitrogen. Although the oxidation ditch mixed liquor used to seed the batch units contained active nitrifying bacteria, evidence of nitrification, i.e., the presence of either nitrite or nitrate nitrogen, was not observed in either study until day 4 of aeration. Figure 12 shows the changes of ammonia and oxidized forms of nitrogen that are representative of both studies. The large initial increase in the concentration of ammonia nitrogen in both Study I (Figure 12) and in Study II, reflects the

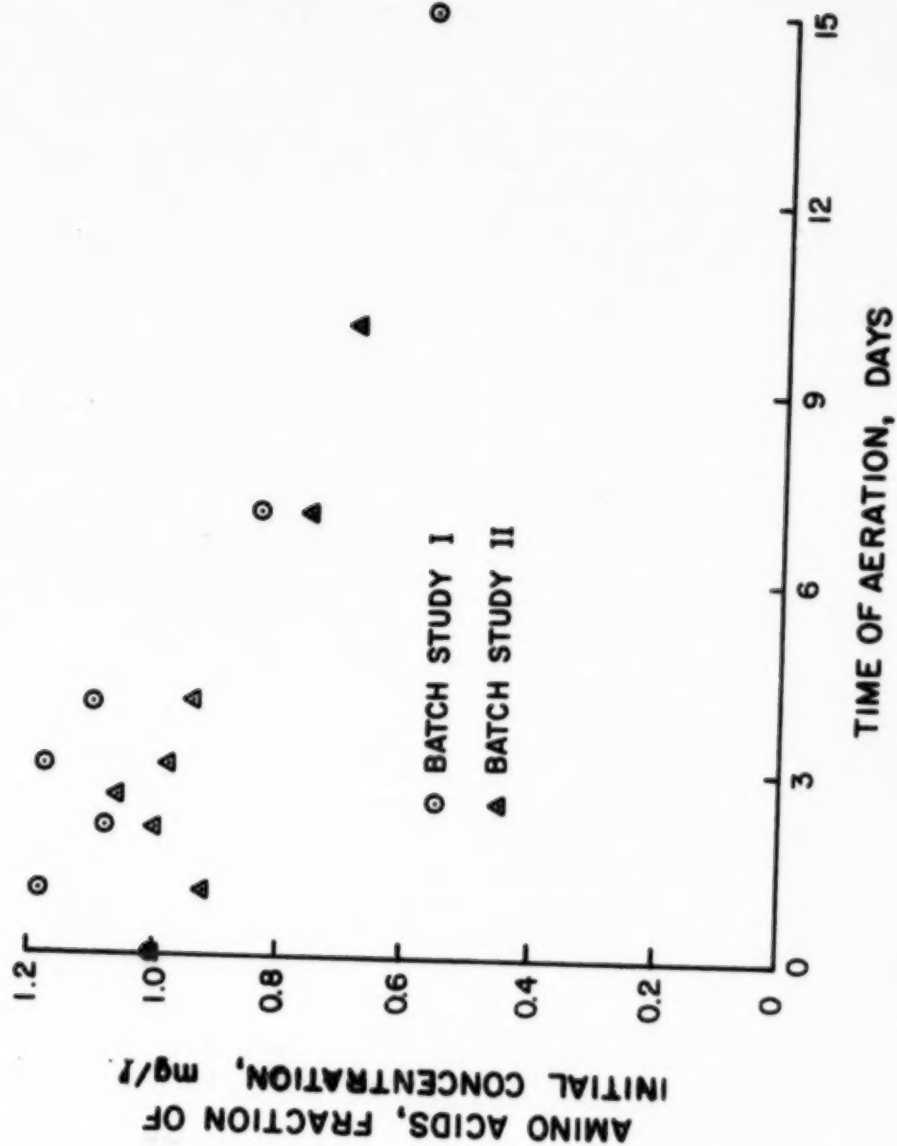


Figure 4. Mixed liquor amino acid concentrations, expressed as fractions of initial concentrations, as a function of aeration time during batch aerobic stabilization.

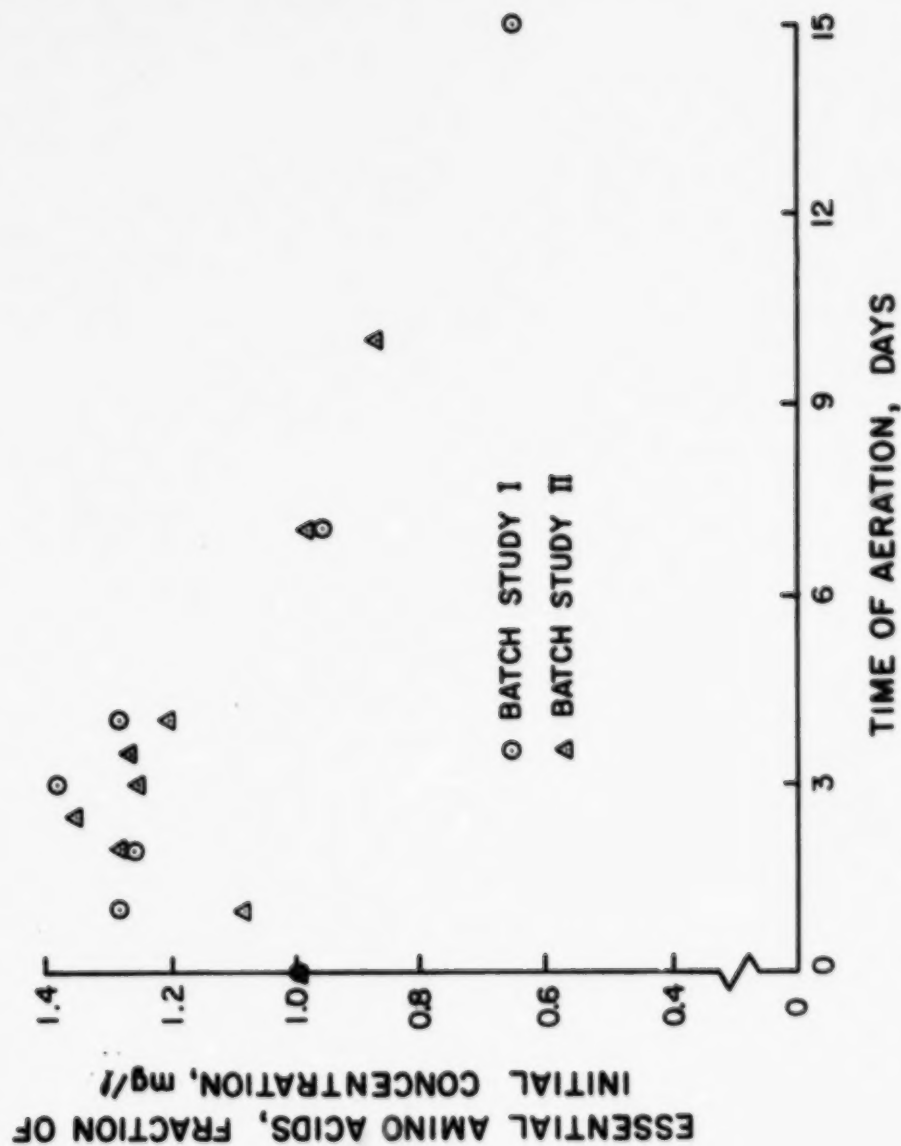


Figure 5. Mixed liquor essential amino acid concentrations, expressed as fractions of initial concentrations, as a function of aeration time -- batch studies.

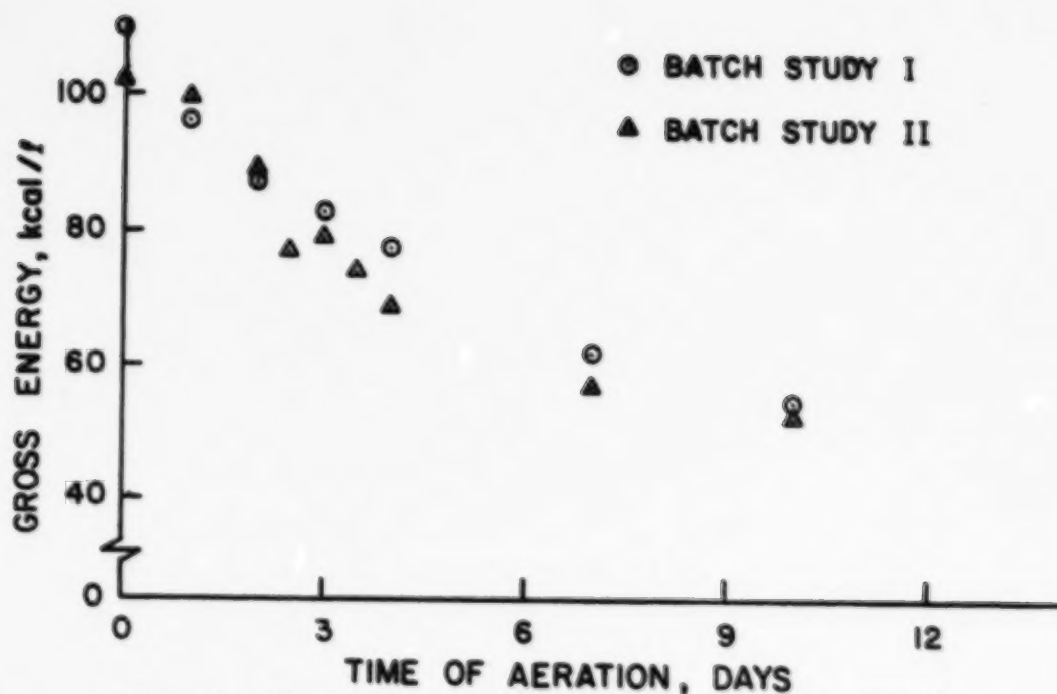


Figure 6. Mixed liquor gross energy concentrations, Kcal/l as a function of aeration time -- batch studies.

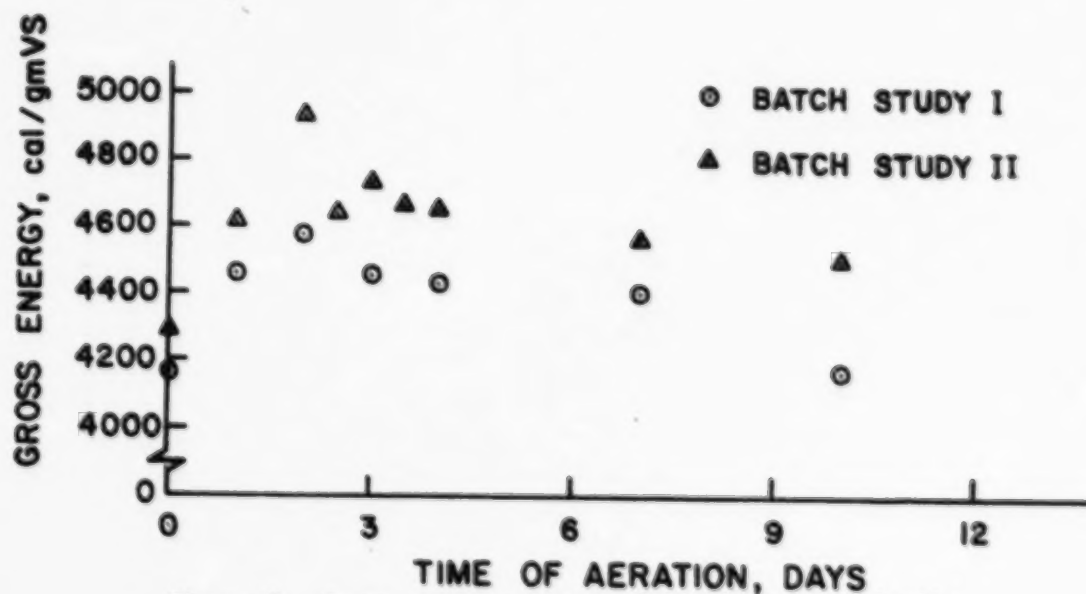


Figure 7. Gross energy content of mixed liquor volatile solids, cal/gm VS, as a function of aeration time -- batch studies.

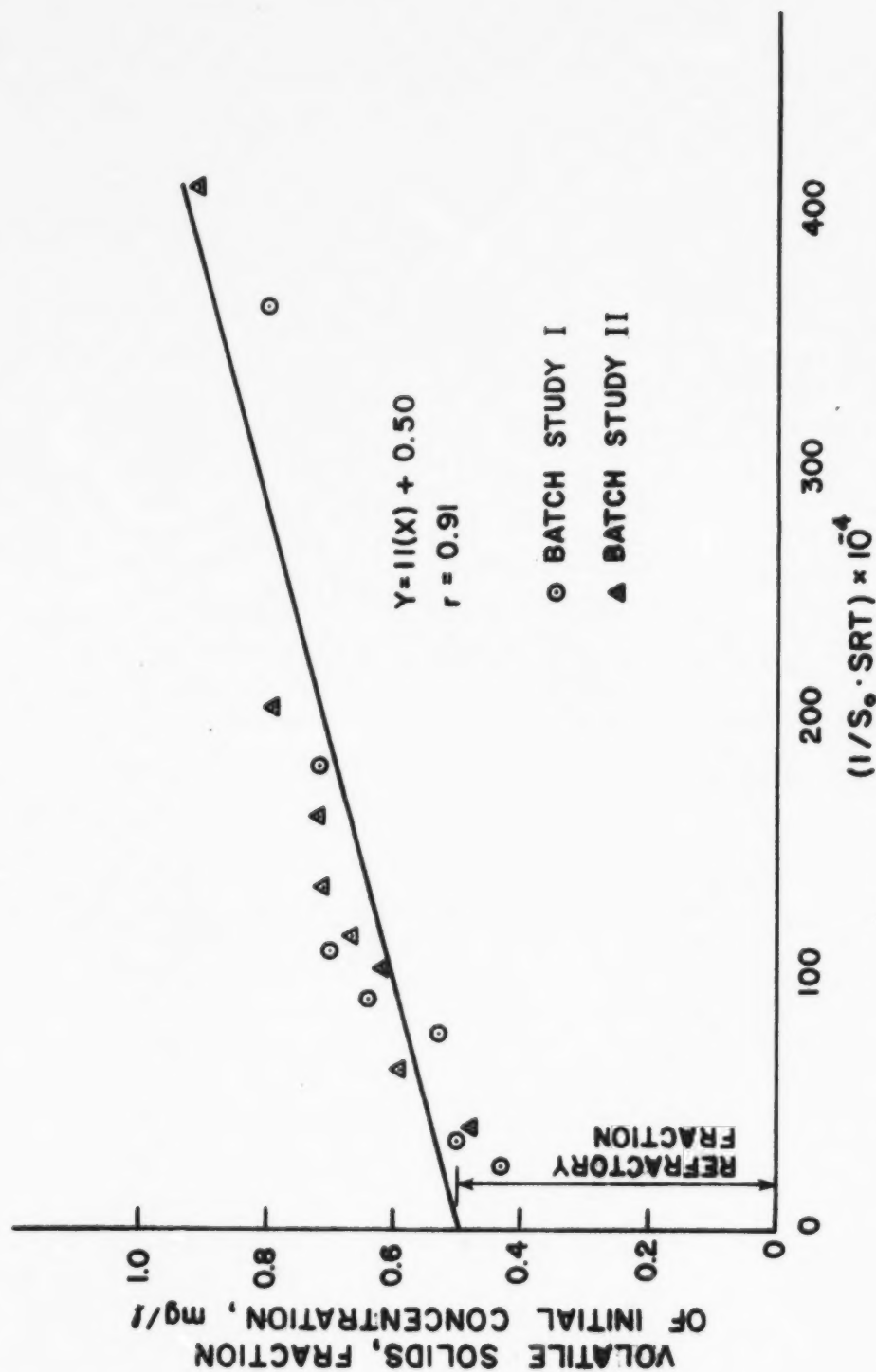


Figure 8. Graphical determination of biodegradable and refractory fractions of laying hen manure volatile solids.

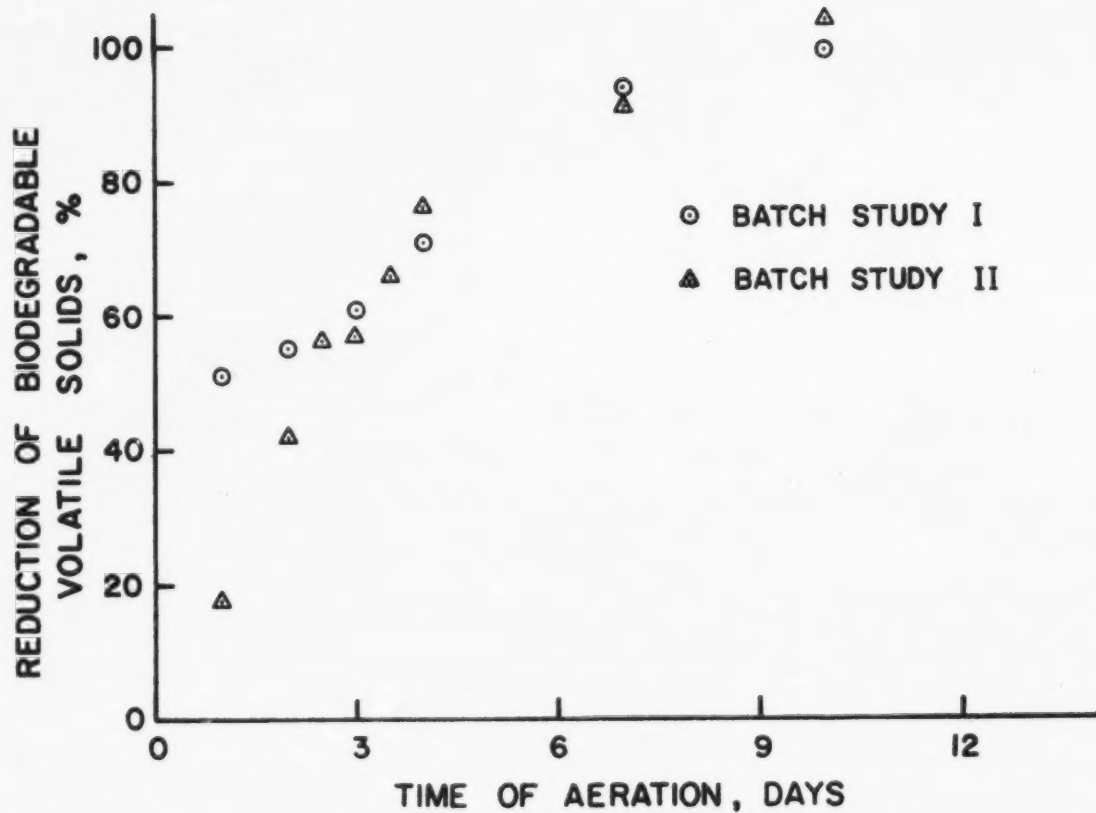


Figure 9. Reduction of the biodegradable fraction of laying hen manure volatile solids as a function of aeration time during batch aerobic stabilization.

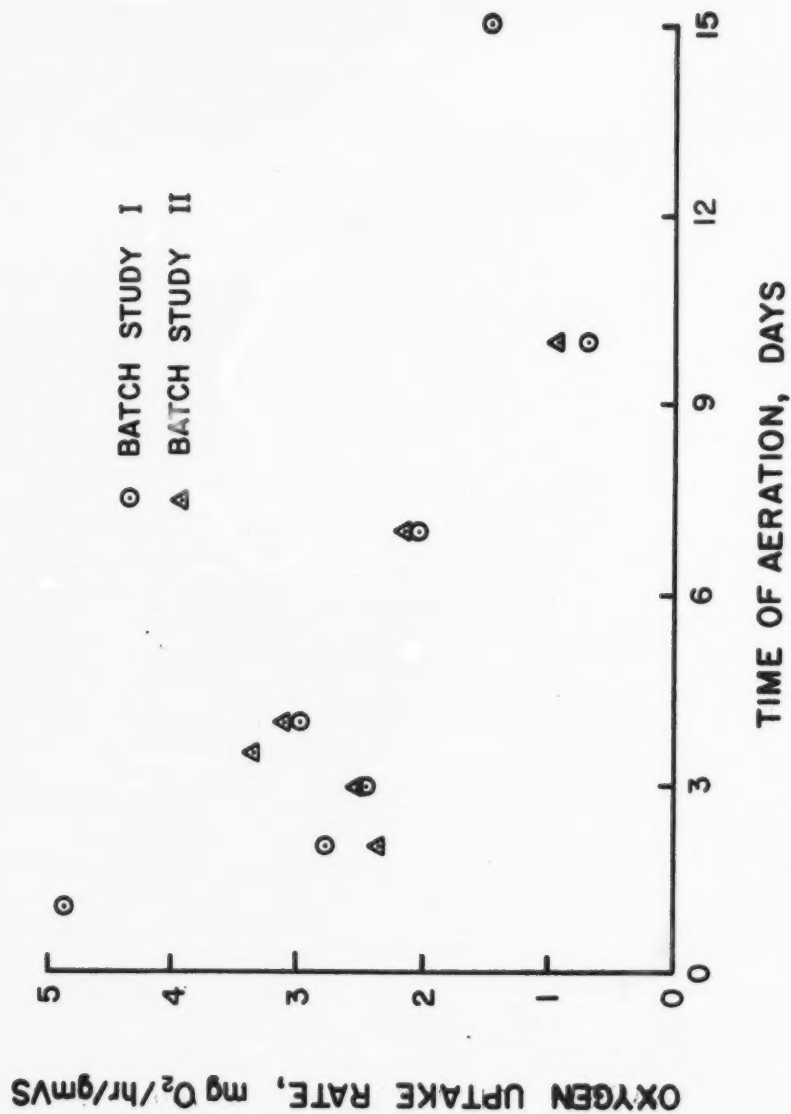


Figure 10. Oxygen uptake rates as a function of time of aeration -- batch studies.

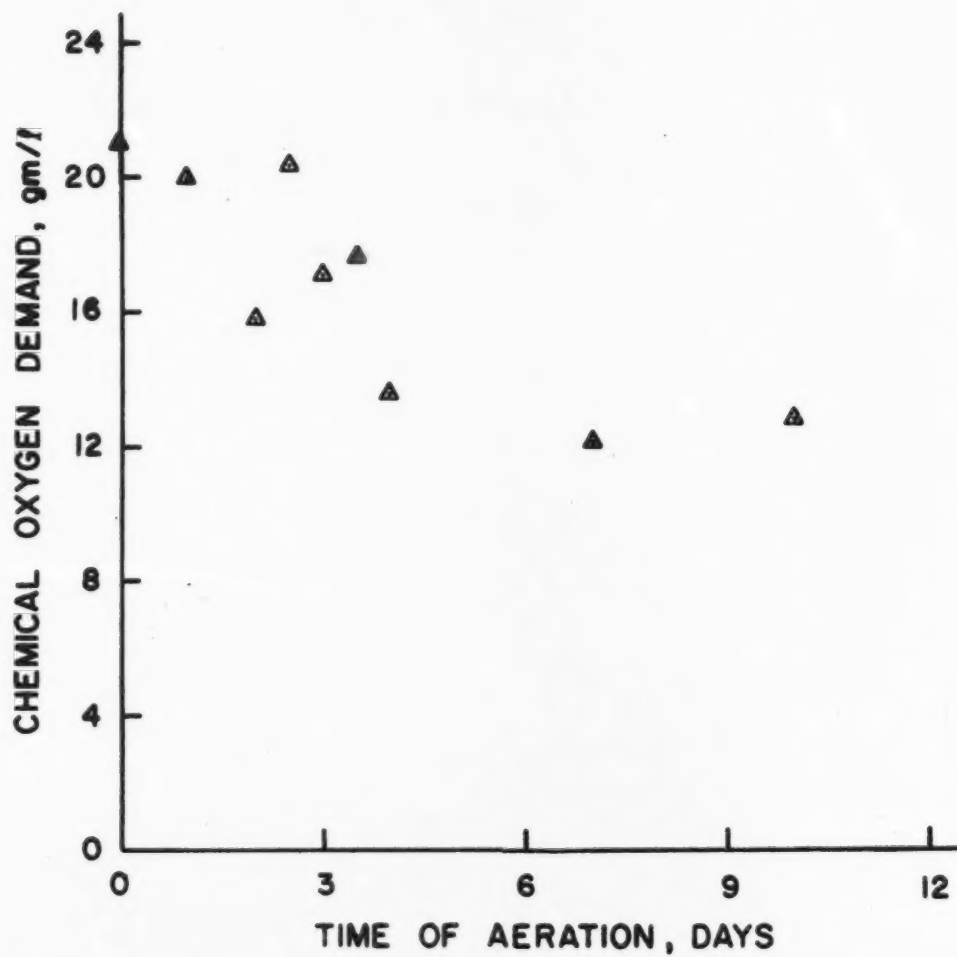


Figure 11. Mixed liquor chemical oxygen demand as a function of time of aeration -- batch study II.

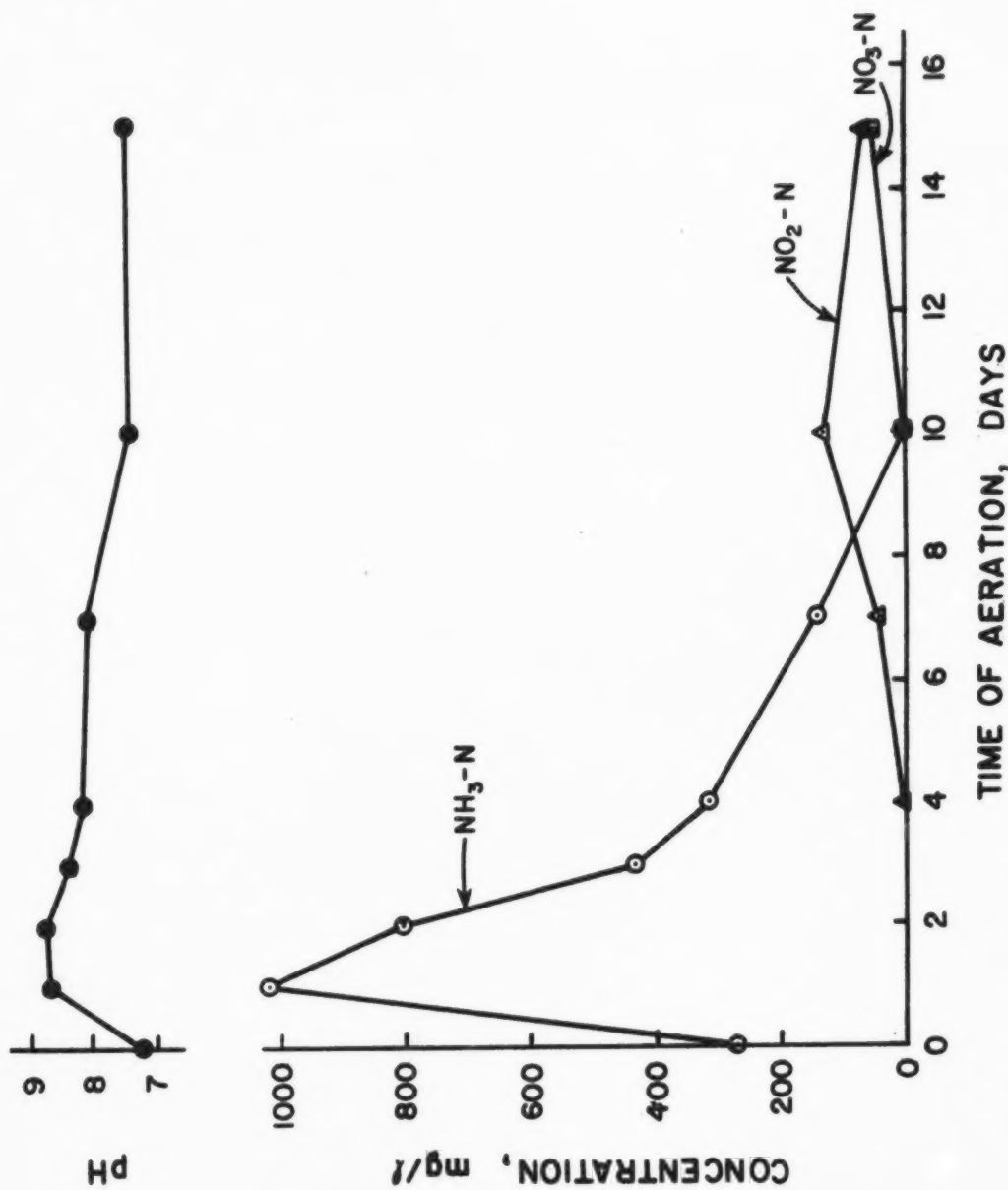


Figure 12. Mixed liquor concentrations of ammonia and oxidized forms of nitrogen -- batch study I.

rapid microbial degradation of organic nitrogen, ammonification, which occurred during the first 3 days of aeration (Figure 13).

Although amino acid nitrogen constituted a relatively constant fraction of initial total nitrogen during the first three days of aeration (Figure 14), it became an increasingly larger fraction of the remaining organic nitrogen during this period (Figure 15). This is indicative of an increase in the potential value of the remaining organic nitrogen as a source of protein.

CONTINUOUS FLOW STUDIES

Following the completion of the two batch studies, continuous flow condition studies were undertaken. The continuous flow reactors were operated at solids retention times (SRTs) of 3, 5, 7 and 10 days. The following summarizes the results obtained under steady-state conditions.

Results of analyses to determine amino acid content and composition for each retention time are compared with influent values in Table 16. These data show changes in amino acid composition similar to those observed in the two batch studies (Tables 13 and 14). The percent of essential amino acids were greater in units having the shorter SRT values.

As shown in Figure 16, the apparent increases in amino acids at SRTs of 3 and 5 days (Table 16) were due to decreases in mixed liquor total solids concentrations (Figure 17). Even with short term aeration, 3 day SRT, the mixed liquor concentration, mg/l, of total amino acids decreased slightly (Figure 16) although there was an increase in the concentration of essential amino acids. At retention times exceeding 3 days, concentrations of both total and essential amino acids decreased rapidly. Thus aerobic stabilization units with long SRT values (>3 days) will have lower amino acid concentrations in the mixed liquor.

Changes in mixed liquor concentrations of total and volatile solids (Figure 17) and chemical oxygen demand (Figure 18) as a function of retention time indicate that retention times exceeding 3 days provide little additional benefit with respect to waste stabilization. This conclusion also is supported by the observed decrease in oxygen uptake rates as SRT increases (Figure 19).

As shown in Figure 20, the retention time of 3 days was not adequate to maintain an active population of nitrifying bacteria as indicated by the lack of either nitrite or nitrate nitrogen. This was not unexpected, however, since reported minimum SRT values for *Nitrosomonas* and *Nitrobacter* at 20°C are 2.1 days and 2.9 days, respectively (Stratton and McCarty, 1967). As shown in Figure 21, mixed liquor organic nitrogen consisted almost entirely of amino acid nitrogen at a retention time of 3 days but the amino acid fraction declined as retention time increased.

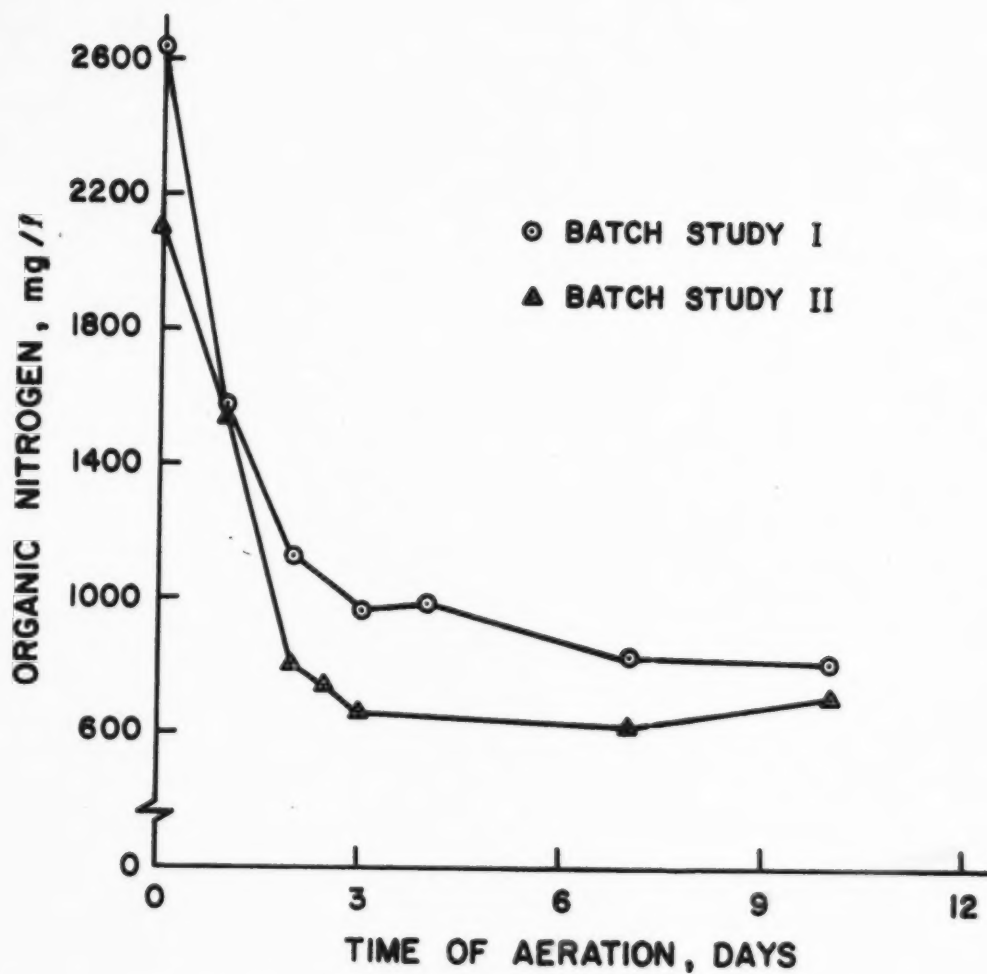


Figure 13. Mixed liquor organic nitrogen as a function of aeration time -- batch studies.

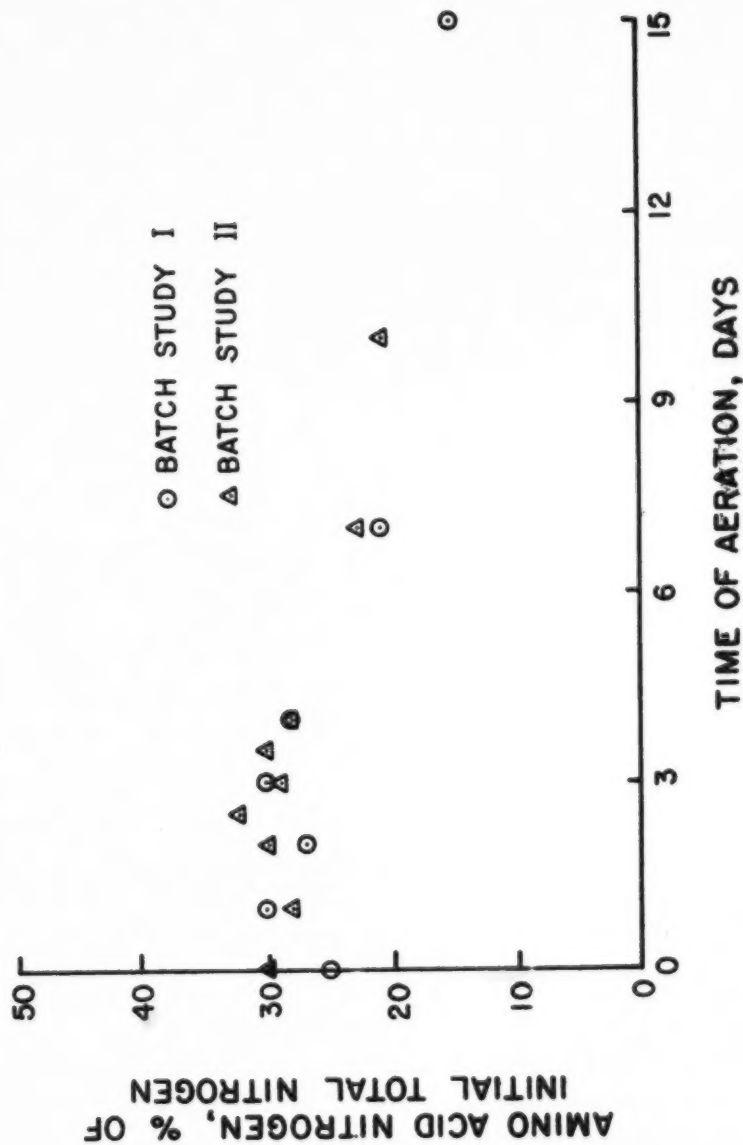


Figure 14. Amino acid nitrogen, expressed as a percentage of initial total nitrogen, as a function of aeration time -- batch studies.

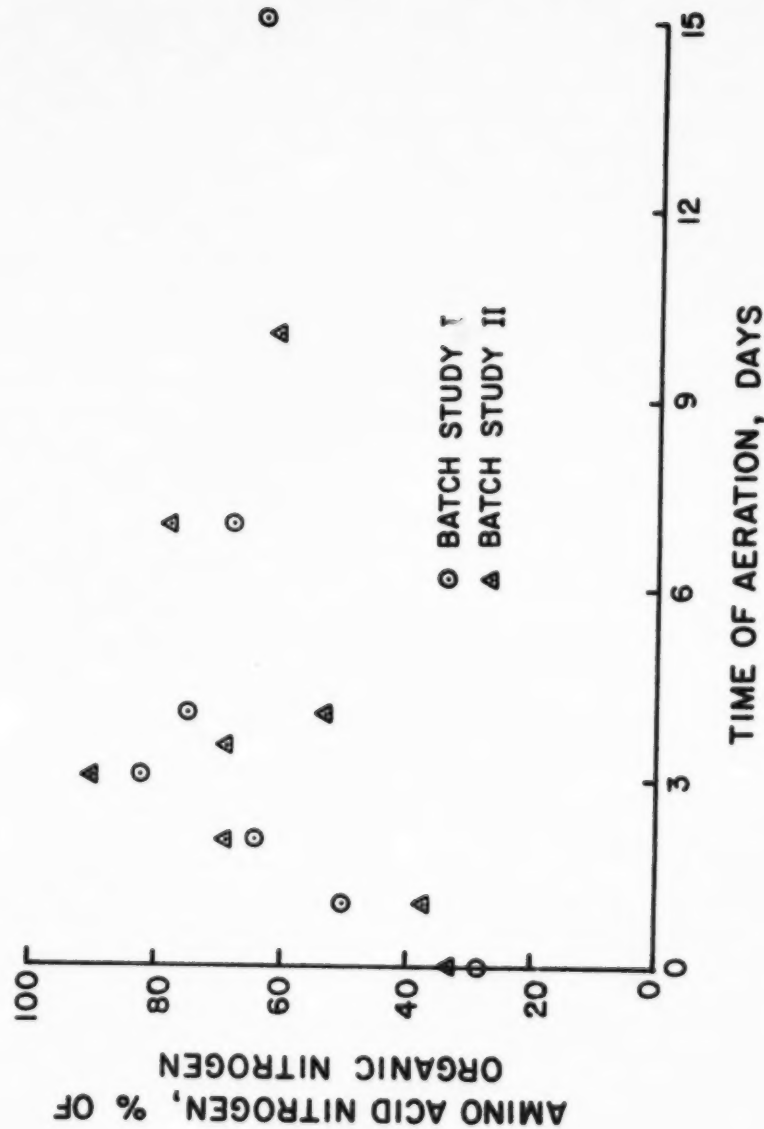


Figure 15. Amino acid nitrogen, expressed as a percentage of mixed liquor organic nitrogen, as a function of aeration time -- batch studies.

TABLE 16. AMINO ACID COMPOSITION OF LAYING HEN MANURE AS A FUNCTION OF RETENTION TIME -
CONTINUOUS FLOW STUDIES.

Amino Acid, % TS*	Retention Time, Days				
	Influent	3	5	7	10
Alanine	1.06	2.11	1.74	1.54	0.78
Arginine†	0.60	1.26	0.56	0.92	0.42
Aspartic Acid	1.41	2.37	1.97	1.73	0.84
Glutamic Acid	1.72	2.70	2.08	1.81	0.88
Glycine	3.81	1.70	1.56	1.39	0.54
Histidine†	0.28	0.36	0.29	0.28	0.11
Isoleucine†	0.90	1.19	1.01	0.91	0.43
Leucine†	0.94	1.63	1.42	1.35	0.73
Lysine†	0.70	1.13	0.61	0.44	0.35
Methionine†	0.24	0.55	0.25	0.33	0.01
Phenylalanine†	0.49	0.86	0.72	0.66	0.13
Proline	0.70	0.94	0.80	0.78	0.62
Serine	0.60	0.96	0.78	0.65	0.08
Threonine†	0.60	1.04	0.83	0.67	0.04
Tyrosine	0.36	0.62	0.44	0.37	0.00
Valine†	0.70	1.34	1.21	1.10	0.63
Total Amino Acids	15.10	20.76	16.27	14.93	6.59
Essential Amino Acids, % of Total	36.0	45.1	42.4	44.6	43.2

* % of total solids (dry matter).

† essential amino acids.

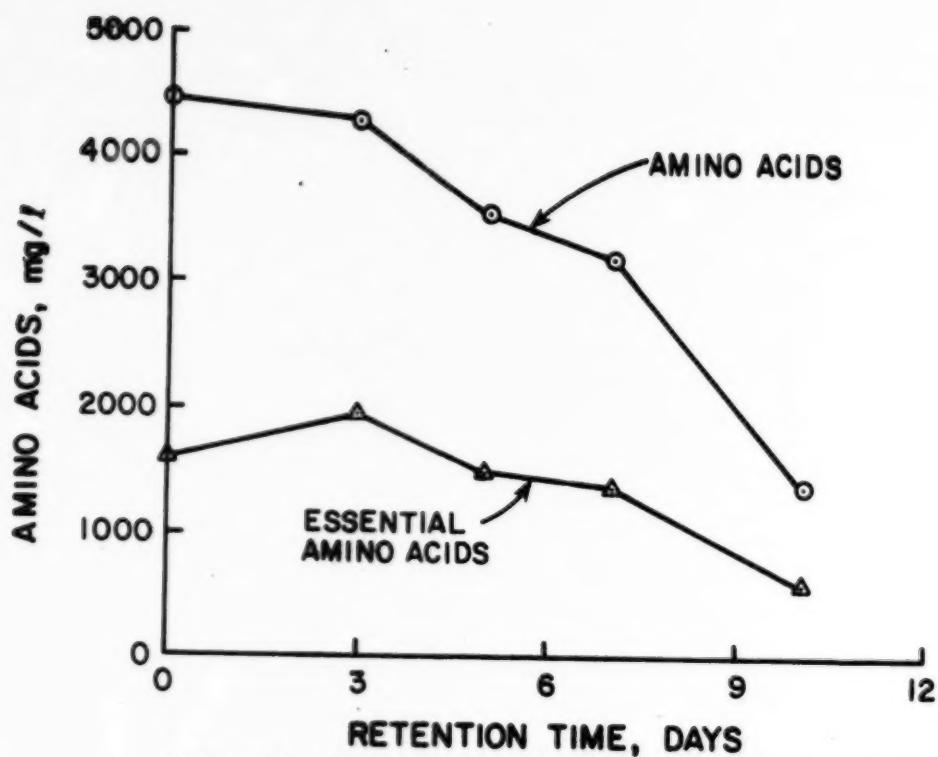


Figure 16. Relationships between total and essential amino acid concentrations and retention time -- continuous flow studies.

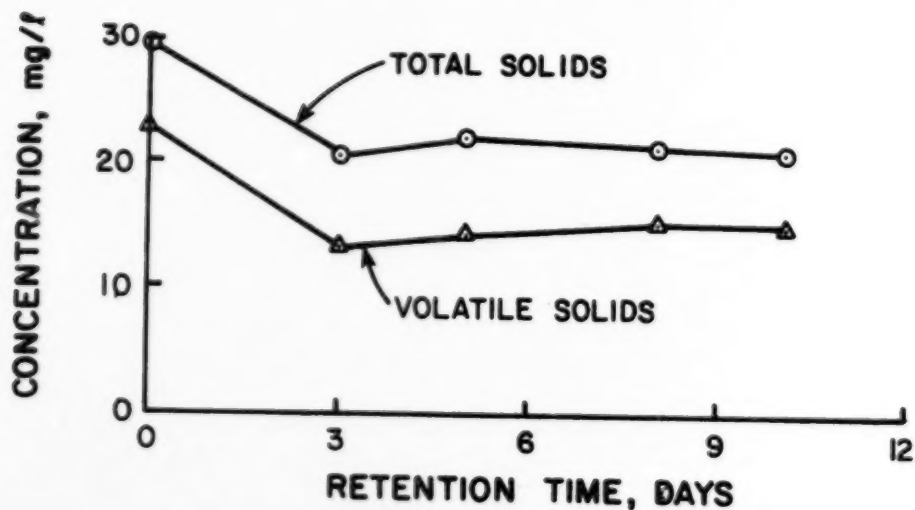


Figure 17. Relationships between total and volatile solid concentrations and retention time -- continuous flow studies.

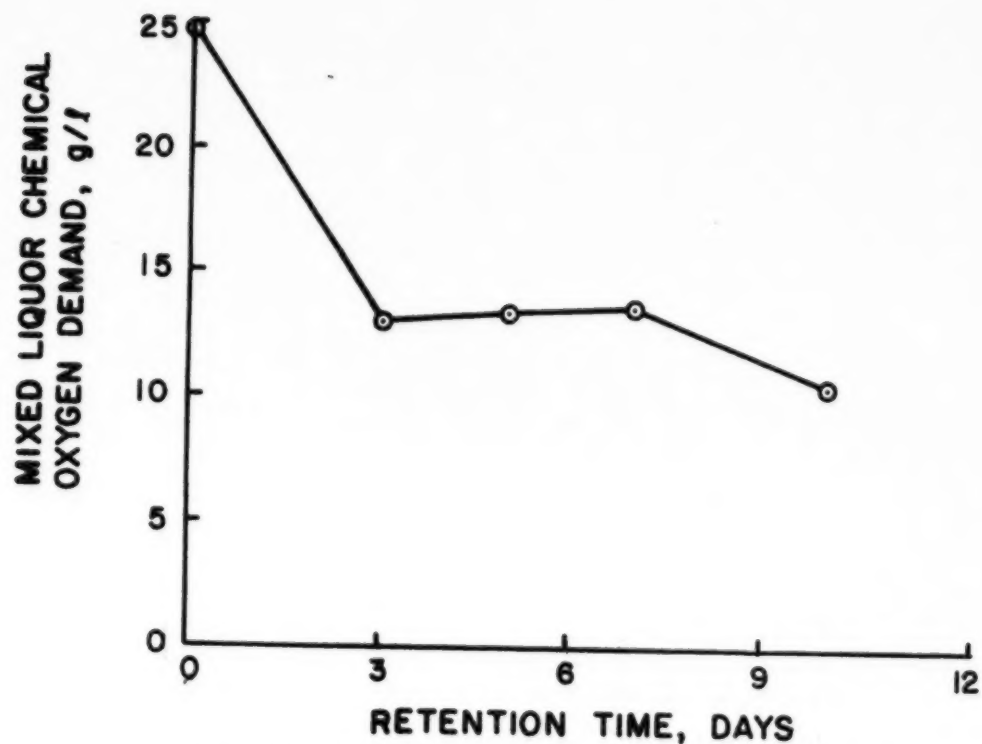


Figure 18. Relationship between mixed liquor chemical oxygen demand concentrations and retention time -- continuous flow studies.

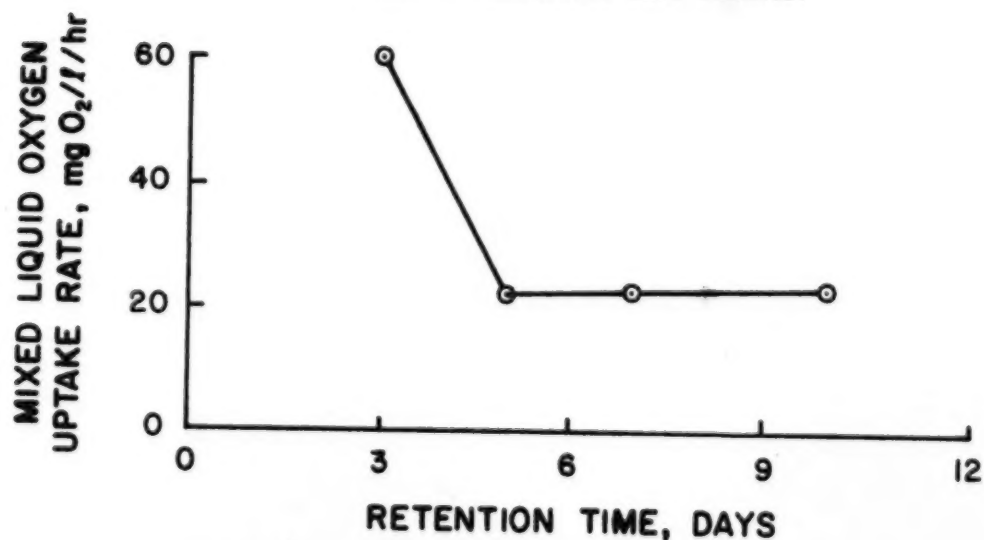


Figure 19. Relationship between oxygen uptake rates and retention time -- continuous flow studies.

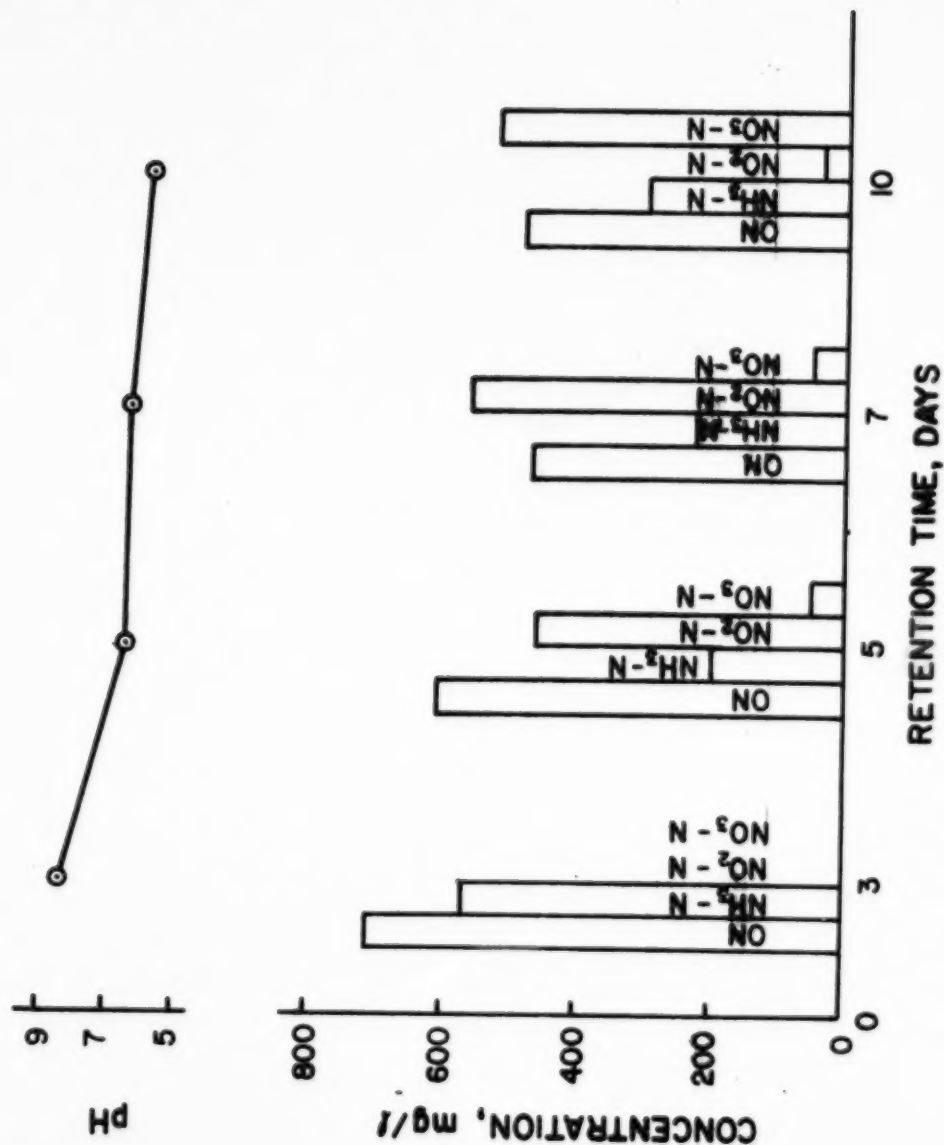


Figure 20. Mixed liquor concentrations of organic, ammonia, nitrite, and nitrate nitrogen -- continuous flow studies.

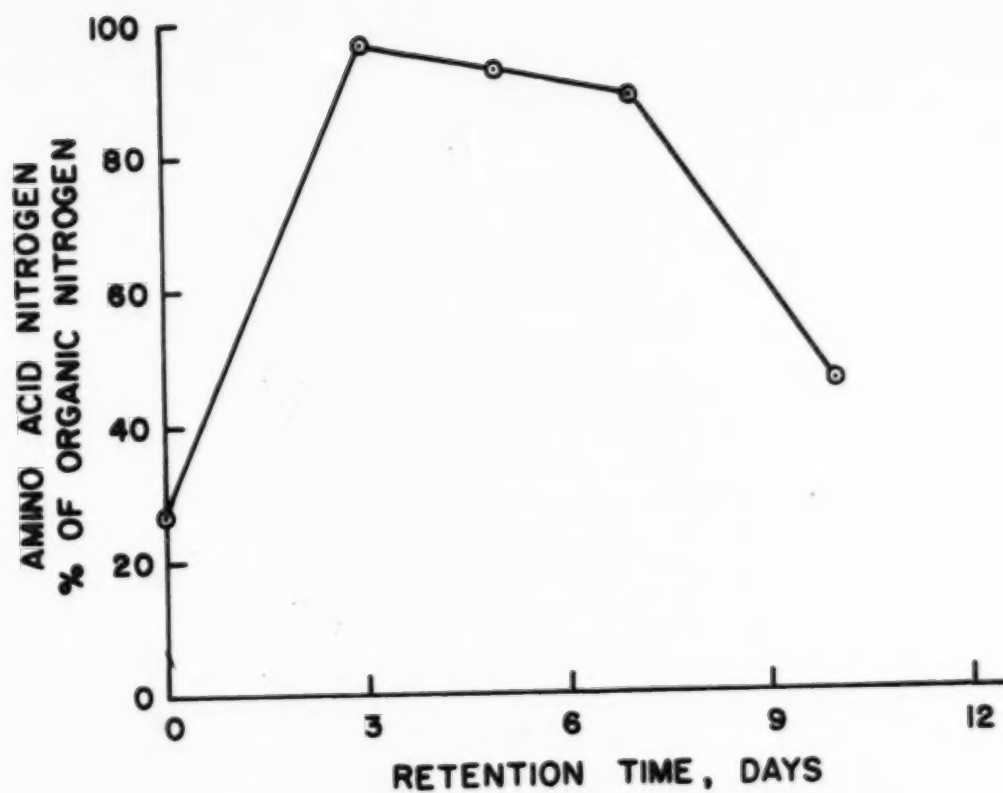


Figure 21. Relationship between amino acid nitrogen expressed as a percentage of organic nitrogen and retention time -- continuous flow studies.

SUMMARY

The results of these studies indicate that short term aerobic stabilization, about three days under batch conditions and at a retention time of three days or less under continuous flow conditions, significantly enhances the value of laying hen manure as a source of essential amino acids. These results also show that the stabilization of readily biodegradable carbonaceous compounds present as constituents of laying hen manure is essentially complete within three days of aeration. Thus, waste stabilization and amino acid enhancement can be complementary objectives.

SECTION 5

DISCUSSION

The results of this investigation indicate that the essential amino acid content of laying hen manure can be substantially increased with short-term aerobic stabilization. This is of little significance, however, unless the amino acids produced have nutritive value and can be utilized under commercial conditions to reduce the protein content and thus the cost of practical diets.

NUTRITIVE VALUE

The nutritive value of any feedstuff including aerobically stabilized laying hen manure as a source of protein depends on its ability to supply all required amino acids, particularly essential amino acids, in appropriate amounts. Unlike freshly excreted laying hen manure, aerobically stabilized manure appears to be a well balanced source of amino acids for laying hens with the exception of marginal deficiencies in histidine and phenylalanine (Table 17).

Aerobically stabilized laying hen manure also compares favorably with soybean meal particularly as a source of methionine and appears superior to cottonseed meal, peanut meal, and corn gluten meal as a source of essential amino acids (Table 18). Soybean, cottonseed, peanut and corn gluten meals are the principle plant protein sources used in the formulation of practical diets for poultry.

Although the amino acid composition of aerobically stabilized laying hen manure indicates that this material should be a good source of protein for laying hens, it should be recognized that the nutritive value of this material can only be determined by biological methods such as measurements of protein digestibility. The physio-chemical methods used to determine amino acid composition provide no information concerning digestibility and release of essential amino acids in the digestive tract.

UTILIZATION

As noted in Section 1, aerobically stabilized laying hen manure has been used successfully in feeding trials as a substitute for tap water in the diet of White Leghorn laying hens (Martin, 1980). In that study, mixed liquor from an undercage oxidation ditch operated as a continuous flow reactor was circulated continuously through a trough-type watering system

TABLE 17. COMPARISON OF THE AMINO ACID COMPOSITION OF AEROBICALLY STABILIZED AND FRESHLY EXCRETED LAYING HEN MANURE WITH LAYING HEN AMINO ACID REQUIREMENTS.

Amino Acids	----- Amino Acids Supplied by 20 gm of Protein -----		
	Laying Hen Requirements*	Aerobically Stabilized Laying Hen Manure+	Freshly Excreted Laying Hen Manure†
Arginine	1.0	1.21	0.79
Lysine	0.84	1.09	0.93
Histidine	0.4	0.35	0.37
Methionine	0.4	0.53	0.32
Cystine‡	0.32	#	#
Tryptophan	0.2	#	#
Phenylalanine	0.92	0.83	0.65
Leucine	1.5	1.57	1.24
Isoleucine	1.0	1.15	1.19
Threonine	0.74	1.00	0.79
Valine	0.86	1.29	0.93

* Scott et al. (1976).

+ This study - 3 day continuous flow effluent (Table 16).

† This study - (Table 16).

‡ Not an essential amino acid for poultry; can be synthesized from methionine.

Not determined.

TABLE 18. COMPARISON OF THE AMINO ACID COMPOSITION OF AEROBICALLY STABILIZED LAYING HEN MANURE WITH SEVERAL PLANT PROTEIN SOURCES.

Amino Acids	----- Amino Acids Supplied by 20 gm of Protein From: -----				
	Aerobically Stabilized Laying Hen Manure, gm†	Soybean Meal, gm*	Cottonseed Meal, gm*	Peanut Meal, gm*	Corn Gluten Meal, gm*
Arginine	1.21	1.4	2.15	2.36	0.65
Lysine	1.09	1.3	0.78	0.92	0.37
Histidine	0.35	0.48	0.54	0.48	0.42
Methionine	0.53	0.30	0.29	0.16	0.47
Cystine‡	#	0.33	0.49	0.28	0.33
Tryptophan	#	0.26	0.24	0.20	0.11
Phenylalanine	0.83	0.96	1.07	0.92	1.12
Leucine	1.57	1.48	0.17	1.48	3.06
Isoleucine	1.15	1.08	0.78	0.80	0.98
Threonine	1.00	0.76	0.68	0.56	0.60
Valine	1.29	1.08	0.98	1.12	1.02

* Scott et al. (1976).

† This study, continuous flow reactor - 3 day time (Table 16).

‡ Not an essential amino acid for poultry; can be synthesized from methionine.

Not determined.

with the overflow returned to the ditch. This utilization approach was found to be particularly attractive due to its simplicity and adaptability to commercial conditions. Trough-type, continuous flow watering systems are frequently used in the poultry industry.

In more recent feeding trials conducted at Cornell University, it has been determined that aerobically stabilized laying hen manure slurries containing up to 30 gm/l of total solids can be used as tap water substitutes for laying hens. Although slurries containing higher concentrations are readily consumed, these slurries are too viscous to be used with continuous flow trough-type watering systems. In these recent feeding trials, it also was established that a mature White Leghorn laying hen will consume about 300 ml/day of aerobically stabilized laying hen manure when used as a substitute for tap water. Observed values ranged from 250 ml to 350 ml/hen-day varying with ambient temperatures.

Assuming that mixed liquor total solids are 20% protein (Table 16, 3 day retention time), 300 ml of aerobically stabilized laying manure with a total solids concentration of 30 gm/l contains 1.8 gm of protein. This represents slightly more than 10% of a mature White Leghorn laying hen's daily protein requirement which is 17 gm/day (Scott *et al.*, 1976). This would permit the use of a 16% protein in place of an 18% protein laying ration. The calculated impact of this reduction in ration protein content on feed costs is shown in Table 19. These figures indicate that aerobically stabilized laying hen manure has potentially significant monetary value as a feedstuff. For 30,000 hens, feed cost savings could exceed \$10,000/year.

TABLE 19. AN ESTIMATE OF THE MONETARY VALUE OF AEROBICALLY STABILIZED LAYING HEN MANURE AS A SOURCE OF PROTEIN BASED ON PROJECTED FEED COST SAVINGS.

	Feed Costs*	
	\$/1000 Hens/Year	\$/Dozen Eggs
18% Protein Laying Ration† plus Tap Water	\$6940	\$0.347
16% Protein Laying Ration§ plus Aerobically Stabilized Laying Hen Manure	6595	0.330
Difference	\$ 345	\$0.017

* Assuming: 1) 95 gm of feed/hen-day 2) 1.7 kg feed/dozen eggs.

† \$200.11/tonne, Agway Inc., Ithaca, NY, 1981.

§ \$190.19/tonne, Agway Inc., Ithaca, NY, 1981.

SYSTEM DESIGN

This study has not only demonstrated that aerobic stabilization can significantly enhance the composition of laying hen manure amino acids and thus the potential value of this manure as a feedstuff but also has provided a rational basis for system design. Using this information in combination with the noted assumptions, the following design example for the system shown in Figure 22 was developed. In this design example (Table 20), it was assumed that a solids retention time of 3 days would preclude nitrification and exertion of nitrogenous oxygen demand. Thus, the estimate for oxygen demand was limited to carbonaceous oxygen demand using chemical oxygen demand removed as the basis for the estimate.

The estimated cost for aeration of $\$5.4 \times 10^{-4}$ /hen-day, which translates into \$197/1000 hens/year, compares favorably with the previous estimate for feed cost savings of \$345/1000 hens/year (Table 20). Thus, it appears that even when capital and other operating costs are considered, the potential value of aerobically stabilized manure, as a feedstuff appears adequate to justify the cost of waste stabilization and odor control.

It should be noted that it may be necessary to add an additional process to the flow diagram shown in Figure 22. Although the absence of nitrification is attractive in that it reduces oxygen demand and therefore aeration costs, high residual ammonia-nitrogen concentrations (Figure 20, 3 day retention time) may be toxic to laying hens. Thus, it may be necessary to utilize a process such as air stripping or ion exchange for removal of ammonia nitrogen before using aerobically stabilized laying hen manure as a tap water substitute.

SUMMARY

As indicated in the preceding discussion, the amino acid composition of aerobically stabilized laying hen manure indicates that it should be a good source of protein for laying hens. Estimates of the monetary value of aerobically stabilized laying hen manure as a protein source and aeration costs indicate that this approach for utilizing laying hen manure can be economically feasible.

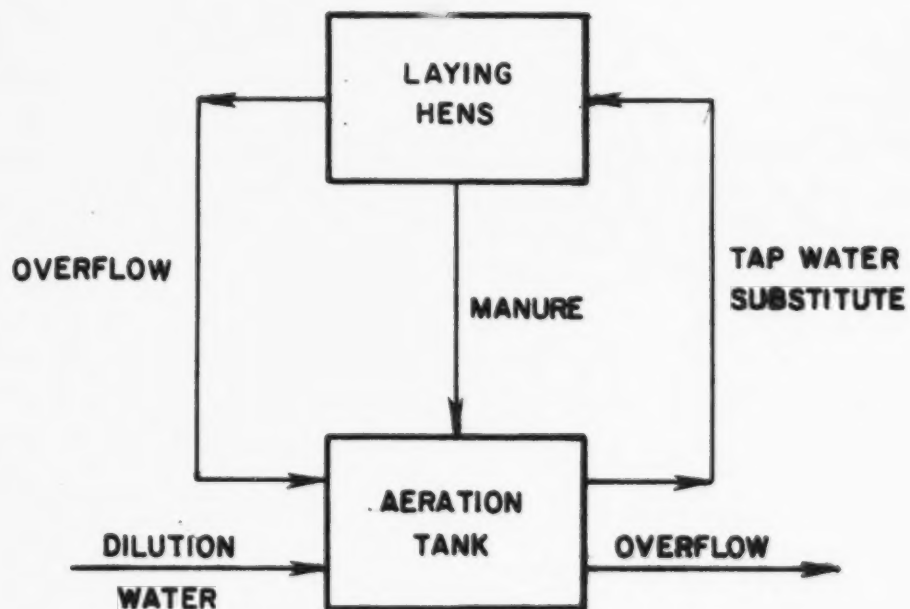


Figure 22. Process flow diagram for design example.

TABLE 20. DESIGN EXAMPLE - A COMPLETELY MIXED, CONTINUOUS FLOW AERATION SYSTEM FOR ENHANCING THE NUTRITIVE VALUE OF LAYING HEN MANURE.

Design Criteria and Assumptions

1. Waste Characteristics*	
- Total Solids	25.1 gm/hen-day
- Chemical Oxygen Demand	20.6 gm/hen-day
2. Operating parameters	
- Solids Retention Time	3 days
- Mixed Liquor Total Solids Concentration	30 gm/l
3. System Performance†	
- Total Solids Destruction	30.5%
- Chemical Oxygen Demand Removed	43.8%
4. Mixed Liquor Utilization	300 ml/hen-day
5. Oxygen Transfer Efficiency‡	1 kg O ₂ /KwH
6. Electrical Energy Cost	\$0.06/KwH

Design Relationships

1. Residual total solids, gm/hen-day = (total solids produced, gm/hen-day) x (1 - total solids destruction, decimal fraction).
2. System volume, l/hen = [(residual total solids, gm/hen-day) x (SRT, days)] ÷ (mixed liquor total solids concentration, gm/l).
3. Dilution water required, l/hen-day = (residual total solids, gm/hen-day) ÷ (mixed liquor total solids concentration, gm/l).
4. Ultimate disposal requirements, l/hen-day = (dilution water required, l/hen-day) - (mixed liquor utilization, l/hen-day).
5. Oxygen demand, gm O₂/hen-day = (chemical oxygen demand, gm/hen-day) x (chemical oxygen demand removed, decimal fraction).
6. Aeration cost, \$/hen-day = [(oxygen demand, gm O₂/hen-day) ÷ (oxygen transfer efficiency, gm O₂/KwH)] x (electrical energy cost, \$/KwH).

Calculated Results

1. Residual Total Solids	17.4 gm/hen-day
2. System Volume	1.7 l/day
3. Dilution Water Required	0.6 l/hen-day
4. Ultimate Disposal Requirements	0.3 l/hen-day
5. Oxygen Demand	9.0 gm O ₂ /hen-day
6. Aeration Cost	\$0.00054/hen-day

* Martin and Loehr, 1977.

† Figures 17 and 18.

‡ Metcalf and Eddy, 1980. $\alpha = 0.85$, $\beta = 1.0$.

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